1950-08

Inspection methods for use on stressed aircraft members of sandwich-type construction.

Abbott, Robert L.

Springfield, Virginia: Available from National Technical Information Service

http://hdl.handle.net/10945/24739

Minneapolis, Minnesota
August 15, 1950

Faculty Committee
Department of Aeronautical Engineering
University of Minnesota
Minneapolis, Minnesota

Gentlemen:

Enclosed herewith is completed thesis submitted to you for approval.

Subject thesis is for partial fulfillment of the requirements for a degree of Master of Science in Aeronautical Engineering.

Respectfully yours,

Robert L. Abbott

INSPECTION METHODS FOR USE
ON STRESSED AIRCRAFT MEMBERS
OF SANDWICH-TYPE CONSTRUCTION

by

Robert L. Abbott

August 15, 1950

TABLE OF CONTENTS

PREFACE

A simple reliable method of inspecting or non-destructively testing bonds between cores and faces of sandwich panels as used in aircraft is needed by the industry. Considerable effort to discover such a method is being expended as the use of these new materials becomes more popular.

The project the writer had in mind at the beginning of this work was to discover a principle upon which methods of inspection could be based that would indicate the internal conditions that existed in a sandwich-material panel. In order to discover the principle desired it was necessary to determine the conditions that should be detected in the inspections. The research revealed that there was very little concrete information about the sandwich materials readily available. It was decided to limit the investigations to flat panels of one type, namely Metalite, an aluminum surface—balsa core—aluminum surface material, and to investigate fundamentally as many different principles that might be applicable to that particular type of construction as the time and equipment available would permit.

The difficulties encountered in locating information on fabrication methods, design specifications, component material, and standard test specifications as well as information on previously attempted inspection methods lead the author to summarize in the report some of the general information acquired during the investigations. The sources of this general information were also carefully referenced in order that anyone attempting to accomplish

a similar objective would be spared the search required to locate this basic information.

The writer wishes to acknowledge the material aid and technical assistance given him by Mr. David G. Reid and other members of the structural engineering division of the Chance Vought Aircraft Division of the United Aircraft Corporation, Dallas, Texas and the cooperation extended by the Forest Products Laboratory, Madison, Wisconsin during his visits to that laboratory. Appreciation is also extended to Professor J. A. Wise, thesis adviser, for his many suggestions and guidance in the preparation of this paper.

SUMMARY

This thesis presents the results of an investigation of the inspection methods and non-destructive test procedures which might be used in locating defective and inferior bonds between the core sections or the core and surface sheet of Metalite.

The report includes a brief discussion of the development and production of sandwich materials, their application in the aircraft industry, and the effects of bond defects on the strength of the material.

The investigations were limited to flat sheets of one type of sandwich material, an end grain balsa core with thin aluminum plate surfaces, produced under the trade name of Metalite.

The simplest and most satisfactory method for detecting areas where the faces of the sandwich are not firmly attached to the core was found to be a simple tapping method--the inspection method used in commercial production at the present time by Chance Vought Aircraft Corporation. This method failed to detect areas of weak bond or to locate open bonds in the core material.

Various methods based on eight basic principles were attempted and are discussed individually in this report. Of the eight principles, only two, the surface deflection principle and the heat conductivity principle, gave indications of being able to detect areas of weakened bond. The methods used in applying the surface deflection principle were all complicated to perform, very limited by the thickness of the surface sheet, and if not carefully controlled could introduce destructive stresses in bond or core

directly under the area being tested. It is doubtful that the principle could be developed satisfactorily for commercial use.

The application of the heat-conductivity principle was simpler and appeared to offer promise for further development. The greatest weakness observed in the applications attempted was in surface temperature scanning. It is believed that by developing a more sensitive and flexible method to determine local surface temperature, the principle might be applied commercially.

Some of the other methods were discovered to have individual advantages for special applications and might well be used in combination with other methods to insure perfection until a reliable general inspection method is developed. These specific advantages include the ability to locate flaws in the core material bond by X-ray, the ability to locate doublers or splice bars by supersonic inspections and changes in core material by the soundness tests, all of which are fully explained in their respective sections of this report.

As a result of the investigations, it was concluded that a four stage method of control and inspection is necessary for use on all Metalite which is to be used as a stressed structural material in aircraft and should include:

1. A complete critical process-control throughout the entire production cycle with controlled destructive tests of companion samples or waste margin material.
2. A careful visual inspection of the surfaces for blisters immediately after the material is removed from the autoclave.
3. A complete "Tapping" inspection by a trained

inspector after final fabrication before assembly.

4. A button-pull surface deflection test of any suspected area and random pulls in areas of known critical stress concentration.

INTRODUCTION

The aviation industry, in attempting to keep pace with the ever-increasing demands for improved performance in airplanes, has been experimenting with various types of airplane construction and airplane materials. One such material which promises to be suitable for fairly general use in the industry is "Sandwich" material.

Sandwich construction consists of a light weight core bonded to strong facing materials, and many combinations of core, face material, and adhesives are possible. Various combinations each offer specific advantages but the combinations which are able to compete with the highly efficient all-metal construction of present day aircraft and that are suitable for general use in modern airplanes are limited.

The U. S. Navy has attempted to encourage and assist the aircraft companies to develop some of these materials through its research and development program. A metal-faced balsa-core combination, now generally known to the industry as "Metalite", has been under development by the Chance Vought Division of United Aircraft since 1942. This material has passed through various stages of development and experimental testing and is now being incorporated in the latest type of production aircraft being manufactured by that company. The faces of the material are made of high-strength aluminum alloy and the core of a low-density balsa wood. The balsa wood core is arranged with the grain of the wood normal to the metal faces as indicated in Fig. 1.

Two different methods of bonding the faces to the core are used in manufacturing the material, both of which are described in detail in Appendix A. One process is a two-stage bonding operation in which Cycleweld C-3 cement is cured on the metal faces and then bonded to the core material with a medium temperature phenolic resin adhesive, Durez 13297. The other process employes a high temperature-setting two-component resin with a thermosetting liquid and thermoplastic powder called Redux. The final curing in both methods may be accomplished in a thermal press or an autoclave, but in order to meet the specifications set up by U. S. Navy, the autoclave curing process is used exclusively.

In developing Metalite, much effort both in the laboratory and fabrication shops has been devoted to determining the best and most positive methods of processing the component parts. Experimental work in the use of high strength metal-to-metal adhesives for bonding metal structures, such as control surfaces, engine cowl flaps, and access doors, was started in the aviation industry before the beginning of World War II. The knowledge and experience gained from that work greatly aided the preliminary development of the bonding required in the development of the new "Sandwich" materials. The cycleweld was developed directly from the best metal-to-metal techniques in use prior to 1942.

The construction in sandwich form is essentially a molding operation in most applications. The application of this construction does much toward the elimination of buckling and increases the stiffness in highly-stressed aerodynamic surfaces. These two characteristics of the material make it superior to the common materials applied in the conventional manner. It can be readily

realized that the stiffness and buckle resistance are dependent on the core material and bond strength between the face sheets and core. The effects of certain defects in the bond upon the strength of test panels subjected to tension and flat edge-wise compression are given in Appendix B. The manufacturing process, forming process, curing process, and material used all affect the bond strength. Therefore, when the material is to be used at high design stresses, the bond condition is the important factor since uniform satisfactory cores can be processed as described in Appendix C.

In the development of the material much research has been conducted to obtain consistently uniform and sufficiently strong surface-to-core bonds, and in present practice good results are obtained by using exacting process controls. However, the possibility still exists that process control will permit some defects to occur—hence, a method of finished product inspection is required to assure a perfect result. A method of inspection is desired to periodically determine the condition of the material throughout its service life.

It is toward determining a principle upon which a simple nondestructive inspection method can be based that the investigations described in this thesis were conducted.

The strength characteristics of the material may be affected by several kinds of imperfections or flaws, the most serious of which are:

1. The lack of bond between the surface sheets and the core material.
2. A split or ruptured core—open bond joints in the core.

3. The presence of weak bond joints between the surface sheets and the core material.

4. A weak bond joint in the core material.

5. A difference in bond strength between surface and core material on opposite sides of the core.

6. A variance in bond strength over the surface sheet area.

7. A defect in core material strength, density or condition.

The conditions causing No. 7 above, can be controlled satisfactorily in the manufacturing process, but should be considered in complete in-service inspections. Due to the limitations of this investigation, Item No. 7 is mentioned, but no further consideration has been given to it.

Destructive tests were relied upon in the development stages to determine the internal conditions, but when the material was made available for practical application, the destructive test methods had to be replaced by other types of inspection.

X-ray techniques were tried but they did not locate the weak bond joints or voids in surface-to-core bonds except in very special cases. It was found, however, that the X-ray inspection was useful to locate doublers, to determine the internal condition of the core material, and to investigate the fit of adjacent core sections, Ref. 1. Hypersonic methods have been investigated and found able to detect the larger bond voids. The method holds promise for future development but has not proved satisfactory for application to production at the present time. A pressure-heat method conducted by returning the panel to the autoclave,

reheating and pressurizing, then suddenly depressurizing it, thereby causing the internal pressure to make blisters appear in the surface material above weak or no bond areas, gave acceptable results and is used to some extent in commercial production to locate weak bond areas. The simplest, most reliable and practical method yet discovered was found to be the tapping or coin method. This method is used extensively throughout the industry. Commercial production of the Metalite used in Navy contracts is inspected by the last two methods mentioned above.

In an attempt to find a more applicable positive flaw detection method, eight additional basic principles have been investigated. They are:

1. Heat Radiation Principle
2. Thermal Conductivity Principle
3. Heat Absorption Principle
4. Brittle Lacquer Applications
    a. Vibration Effect
    b. Heat Effect
    c. Flexure or Bending Effect
5. Blast or Shock Principle
6. Sonic Vibration Principle
    a. Tuning Fork Response
    b. Oscillograph Indications
        1. Direct Pick-Up mechanically connected to plate.
        2. Sonic Pick-Up operating through pyramidic chamber
        3. Sound Propagation Methods

c. Fine Particles Vibrating on Plate Surface

1. Metal Filings

2. Talcum Powder

3. Silicon Powder

4. Fine Particles suspended in a liquid

d. Smoke Convection Patterns

e. Oil Film Detection

1. Suspended on Water

2. Free on Vibrating Surface

3. Droplets

7. Surface Contour Methods

a. Visual Inspection

b. Surface Under Vacuum

1. Visual Inspection

2. Mechanical Measurement of Deflections

a. Light Beam Method

b. Ames Dial Application

c. Sudden Pressure Change Method

1. Normal Temperature

2. Autoclave Process Elevated Temperatures

8. Soundness Principle

a. Tapping

b. Bouncing Steel Ball Test

c. Sand Blast on Painted Surface

METHODS OF FLAW DETECTION IN METALITE

Methods Currently Used

In the actual production of Metalite the final inspection is made in two ways. After the final bonding operation the panel is placed uncovered in the autoclave and subjected to the same temperature and pressure conditions as were applied during the bonding. The internal pressure thus built up in the panel will cause a bulge in the face immediately after removal from the autoclave if a weak bond or void exists. The second method used is the tapping method. In this method the faces of the panel are tapped with a special light weight tapping hammer. Bonded areas produce a sharp, solid sound. Void areas are indicated by a dull sound. This method has proved very reliable in practice and is widely used.

In addition to the two methods described the obvious visual inspections reveal any major defects such as surface blisters or open edges on a panel that might have been caused by malfunctioning of the curing equipment or molds.

Methods Previously Proposed

Early investigations conducted in 1940 by Dr. Robert Pohlman for the British Naval Gunnery Mission resulted in a method to locate flaws inside metal plated objects and butt welds by the use of sound radiography using the acoustic image principle. Later attempts to adapt this method to the inspection of Metalite

involved equipment so large and complicated that it was not considered practicable in view of the questionable results obtained.

The Sperry Products, Inc. of Danbury, Connecticut conducted some investigations in 1947 using the supersonic shadowgraph principle to detect flaws in laminated materials. The lens system of the equipment was developed and methods of reducing the effect of standing waves, which had previously prevented sufficient penetration of the waves, were discovered but acceptable results were not obtained. Ref. 2. Again in April of 1949 the Sperry Products, Inc. concentrated their efforts on the testing of Metalite. By this time a crystal mount of simple design had been developed for use in the ultrasonic tank, the standing waves had been neutralized and sufficient penetration could be obtained by the use of the higher voltages the new crystal and mount could stand. Thick samples of Metalite, 7/16 in. thick core with as many as seven aluminum layers were tested and readable results obtained. The high voltages required posed particular difficulties on this equipment and its operation but the laboratory results obtained seemed to give conclusive evidence that Metalite sections could be tested successfully for lack of bond in this manner. Ref. 3 describes the equipment and procedure used and concludes that there is a good possibility that the method could be developed into a faster process than the tapping method currently used. A sketch of proposed Metalite testing equipment is included in Ref. 3, but the extent to which this proposal has been developed is not known.

The Chance Vought Aircraft Division of United Aircraft Corporation is the manufacturer of Metalite, and has attempted

various methods of inspecting the finished material. They at one time attempted to use a Brush Hypersonic Analyzer, which had been used successfully by the Ordnance Department for detecting voids in rocket powder sticks and by the Goodyear Aircraft Corporation for bond strength determination in metal to metal bonding. The results of the attempt are given in Ref. 4, but in general the tests gave poor correlation between tensile strength and the analyzer records for both tests using the 50 kcps and the 440 kcps crystal tranducers. The detectable unbonded areas were approximately one inch minimum diameter and areas of weakened bond were undetectable. The method used in the Brush Analyzer should permit the observation of some of the types of defects encountered in Metalite and when the work at Chance Vought was discontinued the report, as given in Ref. 4, indicates that a similar program was being undertaken by the Naval Research Laboratory but information on this program has not been obtained.

The ANC Subcommittee on Wood Aircraft Structures late in 1945 requested the Forest Products Laboratory to evaluate the various inspection methods that had been proposed and also to attempt to develop and evaluate other inspection and non-destructive test procedures for use on sandwich type aircraft construction. This investigation continued from late in 1945 to May 1947 when the results were released in a Forest Products Laboratory Report No. 1569, Ref. 5.

The report listed ten methods of inspection which appeared to offer promise in determining the quality of joints between cores and faces of sandwich panels. They are:

1. Visual Inspection
2. Special Lighting
3. Tapping
4. Supersonic Inspection
5. Exposure to Vacuum
6. Vacuum-Cup Test
7. Internal-Pressure Test
8. Heating Complete Panel
9. Local Heating
10. Button-Tension Test

All of the methods were concluded to have some merit and under certain limited conditions were capable of detecting actual voids or unglued areas between the face and core. The tapping test performed by a specially trained person appeared to be the most practicable and dependable.

None of the tests investigated presented practical and dependable means of inspecting sandwich panels for quality of joints and it appeared that combinations of the test methods would offer little promise of improvements.

Methods Tried In This Investigation

Equipment Used

The transducers used in these experiments were of three sizes and made from standard radio equipment. The smaller was the electro-magnetic mechanism of an earphone with a slender metal probe soldered to its metal diaphragm. For the second, a larger dynamic earphone was modified by cementing a probe to the vibrating cone. The third, the heavy transducer was a five-inch magnetic speaker modified by replacing the base cone ring with a similar ring holding a tripod mounted probe. The three transducers were used interchangeably in the experiments to vary the intensity of the induced vibrations.

Three types of pick-ups were used. One was a standard carbon-crystal pick-up from a five-watt record player in which the needle had been replaced by a stiff metal probe. The second was a modified dynamic pick-up with a metal probe connected to the interior ring of the reception cone. The third was a standard aviation-type carbon lip-microphone with a metal probe soldered to the input diaphragm. The three pick-ups were also used interchangeably, but the modified aviation microphone was the most sensitive and was used most extensively.

Several pieces of supporting equipment were fabricated to hold the transducers and pick-ups, all of which were designed to assure consistent spacing of the equipment, proper pressure between the test equipment and the test sample, and uniform mobility of the testing gear over the surface to be tested. They are shown in the illustrations.

A commercial oscillator capable of producing electrical oscillations from 20 to 20,000 cycles per second, and 2 amplifiers were used to provide the controlled oscillations.

A type 208B DuMont Cathode-Ray Oscillograph was used.

The optics of a Fairchild Aircraft Octant, and its light source were used during one of the surface deflection tests.

A 10 inch dynamic radio-type loudspeaker was used to originate the sound waves and free air vibration fields.

An adjustable spring loaded pick-up holder was fabricated for use in some of the surface scanning methods.

Various simple holders, frames, a smoke chamber, and supporting devices were made, all of which are pictured as used in the experiments.

An Ames-Dial Deflection Gage, capable of measurement to 1/10,000 in., was used in the surface deflection tests and was supported by a specially constructed triangular metal frame.

The vacuum chamber was a $10\frac{1}{2}$ in. diameter double thickness plastic cylinder, reinforced as shown. This cylinder had an aluminum base band and top and contained a tap onto which the evacuator was connected.

The special tapping hammer used is described and pictured in the illustration.

The heating chamber used was an electric Westinghouse domestic oven in which the temperature level was maintained by the oven thermostat. A picture of the oven in use is shown in several of the illustrations.

Two bayonet type and one flat bulb mercury thermometers were used in obtaining chamber and surface temperatures. A commercial Taylor oven thermometer was used to determine exact heating chamber temperature and to calibrate the oven thermostat.

A wooden blast chamber 10 in. by 10 in. by $5\frac{1}{2}$ in., constructed from hard yellow pine and reinforced by steel binding bands, was used in the concussion tests.

Material Used

Test Samples

The Metalite used in the tests was standard production-run Redux process material fabricated in the autoclave to U. S. Navy specifications, Ref. 6, by the Chance Vought Aircraft Division of United Aircraft Corporation.

The preliminary investigations were conducted on two sheets of different thickness with exaggerated defects. The defect in one had been made mechanically by removing one surface sheet and the core material with a circular hole cutter, thus leaving essentially only a flat circular aluminum plate section in a Metalite sheet. The defect in the other had been made by separating the surface material from the core with a thin metal strip, thereby leaving an area of no bond. Fig. 2.

The dimensions of Series 1 samples are:

	Sample 1-1	Sample 1-2
Surface Material Thickness	0.012 in.	0.015 in.
Core Thickness	0.250 in.	0.375 in.
Dimensions (approximate)	4 x 6 in.	$6\frac{1}{4}$ x 7 in.

Later investigations were conducted on larger sheets of the same material as used for Sample 1-2 described above.

A control panel 11 in. by 11 in. was chosen at random from the sections cut out of one large sheet of production-run Metalite which had passed all of the usual inspections required for the material before final fabrication in industry.

Three test panels also 11 in. by 11 in. were prepared from the remaining sections of the same material, each containing a different kind of typical defect in bond joint.

The first, Sample 2-1, made to represent an open bond joint between the surface sheet and core material was prepared by inserting a heated thin metal strip in the surface-to-core bond, thereby opening the bond and causing a void in the material located as shown in Fig. 3.

The second, Sample 2-2, made to represent a weakened bond

between the surface sheet and the core material was prepared by heating one surface of the panel with an electric iron to 425° F. for 30 minutes. The panel in this condition is referred to as Sample 2-2. Later, because of the scarcity of Metalite for use in the tests, this same panel was heated for 20 minutes on the opposite surface in the flame of a gasoline blowtorch, and in this condition is referred to as Sample 2-2b. This latter condition was assumed to represent a condition in which the bond between the surface sheet was completely destroyed, but that there still remained a contact between the core material and the surface sheet. It was suspected that this type of defect might produce results somewhat different from those obtained on Sample 2-1.

The third, Sample 2-3, made to represent overstressed, mechanically broken, or irregularly secured bond joints or ruptured core material in the sample was prepared by loading a simply supported test panel past its yield point with a single concentrated load applied at the center, and then removing the resulting visible deformations with a mechanical press.

The test panels of Series 2 were all inscribed with a reference grid of two-inch squares located and numbered as shown in Fig. 3.

Some tests were conducted on strip samples made of the same material as used for Sample 1-2.

A control strip two inches wide and eleven inches long was selected at random from four identical strips which had been cut from the sheet of Metalite used for the panels of Series 2.

The remaining three strips were prepared and numbered to correlate the defects in the panels of Series 2, Fig. 4.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Sample 3-1 contained a known open core-to-surface bond.

Sample 3-2 had a weakened bond condition, but with the core-to-surface bond intact, created intimate contact between the core and surface material.

Sample 3-3 had an overstressed section in which the condition of the defective core and bond was unknown.

The tests requiring larger panels were conducted on sheets of the same material as used for Sample 1-2 described above.

One, Sample 4-1, 11 in. by 24 in., contained a mechanically ruptured core-to-surface bond, a split core, and an area of suspected weak bond located as shown in Fig. 5.

Another, Sample 4-2, 35 in. by 35 in., had one sound surface used as a control surface, and contained two small core-to-surface bond failures indicated by the visible blisters located as shown in Fig 6.

The third, Sample 4-3, a 26 in. by 29 in. curved aircraft door, contained numerous defective core-to-surface bond areas located as shown in Fig 7. 6a

One other test panel, Sample 5, 12 in. by 12 in. with .012 in. 75 ST aluminum surface sheets on 0.375 in. balsa core contained three areas which had not been coated with adhesive during the fabrication process, located as shown in Fig 8. 7

Tests later performed on tension test biscuits taken from suspected defective areas in Samples 2-2, 2-3, 3-2, and 3-3 indicated that the weakened conditions suspected did exist, Fig 3.

Sample	Tension Test lbs/sq. in.	Percent of Control
Control	1150	100%
2-2	120	10.5%
2-3	325	29%
3-2	250	22%
3-3	300	26%

Tests Performed

Heat Radiation Principle

The basic idea of this section was to determine the effect of the difference in bond conditions beneath the aluminum surface on the rate of cooling of the metal surface.

The initial attempt to check this radiation principle was made by heating Sample 1-2 in a 200° F. electric oven for 15 minutes. The sample was removed and a thermometer attached to a known sound surface area. The surface temperature was taken at two-minute intervals for ten minutes and the average rate of cooling determined. The same sample was reheated and the process repeated with the thermometer attached over a known defective area. Both samples were cooled in the same external environments and the cooling rates computed over the same temperature range, Table I.

The preliminary investigation indicated a cooling rate of

2.5° F. per minute for sound areas and 3.0° F. per minute for defective areas—a difference of 20%. From these results it was concluded that the cooling rate was effected by the internal conditions and that an attempt should be made to apply this principle to a larger more representative sample of the material.

Test Sample 2-1 was heated for 15 minutes on a specially designed rack in an electric oven heated to 200° F. The specimen was then removed and the surface temperature of seven grid center points taken in rapid succession. The process was repeated and the temperatures of the same seven points taken in inverse order. An average of these temperatures, as shown in Table II, indicated that the temperature of the entire surface of the test panel was uniform when removed from the oven. Successive temperature readings were taken at four minute intervals on the same points, the averaging process repeated, and the changes in temperature compared at each point. See Table II. A difference was discovered in the rate of cooling of the points tested. It appeared that the greatest drops in temperature occurred over defective areas as indicated by the results obtained on grids 7 and 8.

Test Sample 2-2 was tested in the same manner. The temperatures obtained in these tests are shown in Table III. A comparison of the averages obtained failed to indicate any logical difference in the cooling rate.

Test Sample 2-3 was also tested in the same manner, and the temperatures obtained are shown in Table IV. A comparison of the averages indicates considerable variation in the cooling rate of the surface stations in the panel.

It was concluded that the principle involved was sound and applicable to a limited degree. The method of surface scanning used was too crude to obtain the necessary results. The results obtained from the tests on Samples 2-1 and 2-3 indicate the method could possibly be refined and used to determine defective material containing open core-to-surface bonds, but that determining the exact boundaries of the defect would be very difficult. The results of the tests conducted on Sample 2-2 indicate that the method would not detect areas of weak bond. It would be necessary to develop a method of taking a complete instantaneous set of temperature readings at many more points located on a much smaller grid to determine the boundaries of the defect. In attempting to detect a weakened bond area, the readings would have to be more accurate, perhaps to the 0.01° F., and taken at more frequent intervals since the rate of cooling varies with surface temperature. The equipment necessary to accomplish adequate surface scanning on a panel of the size being used in these experiments would become very complicated and expensive. The necessary equipment was not available, so further investigation of the method was abandoned in favor of a qualitative method.

In the attempt to study the surface cooling rate qualitatively, Sample 2-1 was heated for 20 minutes on a rack in an electric oven at 200° F., then removed and placed defective side up under the glass covered smoke chamber which had been filled with smoke. The behavior of the smoke was observed during the cooling process.

The only detectable changes which were observed in the smoke

[illegible]

[illegible]

[illegible]

chamber were lightening in color and decrease in smoke density near the walls of the container. No motion of the smoke was detectable nor was there any indication of a pattern developing which would indicate the corner containing the large void area. The method did not indicate the difference in radiation rate of the various surface areas and was abandoned.

Thermal Conductivity

A series of the tests were conducted based on the principle of thermal conductivity. The purpose of this investigation was to determine the possibility of the bond conditions affecting the rate at which Metalite would transmit heat.

By considering the possible internal conditions which might exist in a panel, several situations could occur which would affect this characteristic of the material. The first considered was the presence of a void. Test Sample 2-1 would be analogous to introducing a dead air space which is generally accepted as good insulating practice, and theoretically should reduce the thermal transmission through the area it covered. A second considered was that of weak bond, perhaps caused by uneven application of the bonding plastic, improper curing, or high core absorption of the bond material, Test Sample 2-2. In this case, the density of the internal structure between the aluminum surfaces would be affected, and since the heat transmission is related to density, effects of this condition might be detectable.

The third condition considered was that of uneven or broken bond, Test Sample 2-3. In this case, the density of the internal

structure would not be uniform and might reflect in the thermal conductivity of the material.

It is theoretically possible to determine coefficients of heat transmission, U, for a compound material like Metalite by using the conductivity of the materials, k, the material thickness, x, representing surface coefficients for the material in contact with the air, f, and the unit conductance of an air space, a, if one exists. In thermal conductivity calculation, the coefficient of heat transmission is:

$$U = \frac{1}{\frac{1}{f} + \frac{x_1}{k_1} + \frac{1}{a} + \frac{x_2}{k_2} + \cdots + \frac{1}{f}}$$

but is usually determined experimentally for the particular combination of materials desired. Values for the coefficients are given in U. S. Bureau of Standard Tests, tests conducted by F. B. Rowley at the University of Minnesota, and the A. S. H. V. E. Guide 1936, typical examples of which are:

Balsa Wood		
20 lb/cu. ft.	0.58	k
9 lb/cu. ft.	0.38	k
7 lb/cu. ft.	0.33	k
Aluminum Surface (still air)	1.18	f
Air Space (0.10 in.)	3.0	a
Typical Plastic	10.0	k

An attempt to measure the heat transmitted was made by supporting the test control panel of Metalite in a specially designed cover over a domestic electric oven. The cover was designed to utilize the oven as a chamber in which to provide uniform heating, and the oven's automatic control was used to

[illegible]

[illegible]

$$[illegible]$$

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

[illegible]

maintain a constant temperature. The cover exposed 100 square inches of Metalite surface to the uniform temperature of the heat chamber. Another metal lined, air space insulated, wooden chamber of 500 cubic inches, containing a centrally located bayonet type mercury thermometer covered the opposite side of the Metalite. In the first attempt, the oven and its cover, without the test panel in place, were heated to 100° F. The Metalite and upper chamber were then placed in position, and the temperature rise in the upper chamber recorded at three minute intervals until it reached 95° F. This heating process was repeated four times. The equipment was returned to room temperature for each trial, but the rates of heating obtained were not considered consistent enough to be used to quantitatively compute the amount of heat transmitted. It was then decided to compare the heat conductivity of the test panels in Series 2 qualitatively using this method and equipment. The heat conductivity of the panels was compared by two methods.

Each test panel of Series 2 was inserted in the equipment described above and placed over the electric oven which had been preheated to 150° F. The initial temperature of the air in the 500 cubic inch upper chamber was taken when the equipment was placed over the oven, and periodically at five minute intervals for a heating period of 20 minutes. Fig. 21.

The time required to raise the temperature in the upper chamber each 10° F. was also recorded. The data obtained in these observations is given in Tables V and VI.

The room temperature of 71.0° F. remained constant throughout the test and precautions were taken to assure that the air

[illegible]

[illegible]

[illegible]

[illegible]

circulation in the vicinity of the test equipment remained unchanged. The apparatus used to cover the oven, hold the test sample, and the upper air chamber were cooled to the same initial condition before each test.

The results obtained by determining the temperature increase over equal periods of time, have a maximum variation of 3.5 degrees or 11% in 20 minutes. The greatest increase occurred when Sample 2-1 was being tested, and the smallest when the control panel was tested, thus indicating that a defective panel was a better heat conductor than a sound one, which is contradictory to theory.

The order of known defectiveness and indicated heat conductiveness of the samples ~~are~~[13]:

Most Defective	2-1	Most Conductive	2-1
	2-3		2-3
	2-2		2-2
Least Defective	Control	Least Conductive	Control

The results obtained by determining the time required to increase the temperature in the upper chamber a specified amount, have a maximum variation of 3.5 minutes or 16.2% for a temperature variation of 30° F. These results also indicate the order of conductivity opposite to that predicted theoretically. The data given in Tables V and VI was obtained from one test on each sample. The time to increase temperature each 10° F. was taken between the period readings during the same heating process and may account for the qualitative agreement. The data given is for a

single test on each sample, but the data for the control panel and Sample 2-1 was verified in magnitude and trend by an additional test on each of these samples after the original data was reduced and the indicated conductivity of the panels discovered.

Theoretically, the order of conductivity should be reversed. Hence, it is concluded that this method is not satisfactory.

A combination of the heat transmissibility principle and heat radiation principle was considered, the idea being that perhaps the difference in heat radiation rate from the upper surface might be more marked, or that "cool spots" might exist above defective areas if the panel were heated as described above. The problem of scanning the upper surface for temperature variations was encountered and the smoke convection principle was used. Patterns very similar to, but somewhat more pronounced than those obtained when using the heat radiation principle were obtained, indicating that this method was better than the radiation method. Sample 2-1, containing definite voids, was the only sample tested that gave positive clear indications in all trials, and it is doubtful that indications of their presence would have been noticeable had this sample contained small isolated voids of less than one inch in diameter. Fig 21.

Another method of determining the variation of heat transmissibility was tried qualitatively on the samples of Series 2. A wooden chamber 10 in. by 10 in. by 5 in. was constructed to expose 100 square inches of the sample surface to uniform temperature. A wooden frame containing a glass cover was constructed to fit directly above the heating frame, and the complete apparatus, including an electrical heat generator, was placed in a

refrigerator at a temperature of approximately 40° F. A uniform coating of frost was applied to the upper surface of the Metalite plate. The upper frame and glass cover were placed in position and heat introduced into the lower chamber. The effects of conductivity were visible by observing the darkening of areas of the Metalite plate as the frost on the surface began to melt. Considerable edge effect from the apparatus limited the actual areas which could be studied on the surface, but the pattern of vertical bond joints in the balsa core was visible, and an area of supposedly more dense core material appeared consistently on Sample 2-2. Areas above known voids retained a lighter color longer than the other exposed areas, indicating that this method of surface temperature variation was the most sensitive used to date in the experiments. Two small indications of variation, not before located, appeared on Sample 2-3 both times it was tested, indicating that the conductivity principle was functionable if a sufficiently sensitive means of scanning surface temperatures could be obtained. A method, somewhat the reverse of that described above, was attempted. Warm moist air from an electric clothes dryer was placed in the upper chamber and the lower chamber cooled as rapidly as possible by the introduction of cold air and CO_2. Only two tests each on Sample 2-1 and Sample 2-2 were made with this arrangement because of the difficulty encountered in preventing complete, instantaneous condensation over the entire surface when the warm air first came in contact with the test specimen. The two patterns obtained on Sample 2-1 corresponded with the location of known voids, and in one pattern, a faint indication of vertical core bonds may have been obtained. The two condensation patterns

obtained on Sample C-2 were not consistent, nor was any indication of the area of suspected weak bond obtained.

It may be concluded from this section of the tests that the method is possible, but much harder to use, and perhaps less sensitive than the frost method.

It was finally concluded that the principle of heat conductivity would indicate variations in the internal condition of Metalite. The methods of surface temperature scanning attempted were not sensitive enough to detect the minute variations in surface temperature necessary to locate the smaller core-to-surface bond defects. None of the methods attempted gave conclusive evidence that the principle would indicate areas of weakened bond, although theoretically it should. The indication obtained for exaggerated defects, void areas, were positive, but other indications could have been caused by variations in sound bond thickness, weak bonds, difference in core material density, variation in core moisture content, or experimental errors. Further experimentation would be necessary to establish an interpretation of the indications and determine the capabilities or limitations of the principle.

Heat Absorption Principle

The ability of the material to absorb heat was considered. A homogeneous material will absorb heat over it's entire exposed area at a given rate thereby causing the surface temperature to increase uniformly. An attempt to measure the heat absorption characteristics of the test sample was made by studying the

surface temperature variations which existed after a specimen had been exposed to a uniform heat source for a given time.

Sample 2-1 was exposed to temperatures ranging from 150° F. to 325° F. on a specially designed rack in the electric oven for periods of 1, 3, 5, 10, and 15 minutes. The surface temperatures of grids 7 and 19 were taken after each exposure and it was found that the maximum difference of 3° F. between these two locations occurred with a five minute exposure at 250° F. The control panel and samples of Series 2 were then exposed five minutes at 250° F. and the surface temperatures of odd numbered grid areas taken. The temperature readings obtained were erratic and did not show the relationship expected. Using the control panel a series of three identical tests was run. The temperature patterns obtained proved conclusively that the method was not applicable, Fig. 8. Further experimentation indicated that longer exposures would produce uniform surface temperatures, and that a short exposure to a high temperature caused an uneven surface temperature pattern on the control panel which was known to be of sound construction.

The experimentation indicated that the exposure determined from the original tests on Sample 2-1 was applicable only to the condition of that sample and not to the material in general.

It was concluded that the heat absorption characteristics of the material were influenced by factors other than bond defects and that the influence of bond conditions compared to the other factors was not great enough to dominate the heat absorption characteristics of the material. Hence it was considered that the principle of heat absorption was not applicable as a method of

inspecting the internal bond condition in Metalite.

Brittle Lacquer Applications

An attempt to use brittle lacquer to locate areas of defective bond or core material in Metalite was made.

Since the bond condition influences the relative deflection of the core to the surface material in sandwich construction, it was thought that indications of defective bond might be obtained through the surface strain indications obtainable with brittle lacquer.

Samples 1-1 and 1-2 were coated with a thin coat of brittle lacquer and tested in five different ways.

The Test Sample 1-1 was secured by gripping a maple wood frame block attached to the short edge of the sample in a vice, thereby rigidly securing the specimen in a vertical position. A five-ounce mechanical vibrator was then attached by means of a prod to the specimen in the center upper portion of the surface-to-core bond and caused to vibrate at 20 to 20,000 cycles per second. No indications were obtained in this attempt. The test was repeated using a Vib-A-Tool unit instead of the mechanical vibrator but again no results were obtained.

The experimental set-up was then modified to permit the body of the Vib-A-Tool to be rigidly supported perpendicular to the surface of the sample and also adjustable in that direction. This arrangement made the full power of the tool available for a vibration perpendicular to the surface of the test samples, and permitted the sample to be loaded as an end-loaded simple cantilever

support. With only slight initial loading, vibrations did not cause any indications. When sufficient initial load was applied, indications as shown in Fig. 9 occurred.

Sample 1-2 loaded in the same manner required considerably more initial loading, and when indications did occur, they failed to reveal the location of the known defects. From the results of these two trials it was decided that this method was not applicable, and this part of the investigation was discontinued.

The Test Sample 2-1 was cleaned and coated with the lacquer. In this application, the lacquer was applied with a small artist's spray in such a manner as to have one very light covering on part of the known defective area, two coatings over another section, and three coats over the remainder. This was done, even though contrary to the general application instructions, in an attempt to see if the thickness of the lacquer coating would have any effect upon the sensitivity of the method. The sample was then placed in the electric oven heating frame over a 200° F. heating chamber. The arrangement was such that it was impossible to continually observe the heating effects, but when the specimen was removed after a ten minute exposure, there were random check patterns over the entire surface. The only conclusion which could be drawn from the results was that the thinner lacquer coating was more sensitive to heat than the thicker coatings. There were no definite indications of defective areas. However, since the location of the defective areas was known, some pattern variation over these areas could be imagined. Under actual test conditions it would be impossible to locate a defective area by this method.

Another modification of the above was tried with a small

[illegible]

[illegible]

[illegible]

[illegible]

piece of scrap material. The sample shown in Fig 10 had a mechanical void made in the area shown by separating the surface metal from the core with a thin metal knife. The edge was sealed with sealing wax, the surface chemically cleaned and spray-coated with brittle lacquer, and dried in a cool basement room (50° F.). This piece was then horizontally supported on a special four-point suspension rack in the electric oven and heated. This arrangement permitted fairly even heating and continual observation of the coated surface. In this trial it was impossible to determine surface temperatures. Surface checks appeared near the center of the known void areas and around the edges of the sheet, especially along the curved edge before random checking and peeling set in.

Because of the unknown temperatures occurring in this method (temperatures above 300° F.), and the necessity to retain the regular test samples of Series 1, 2, and 3 in their "cure" condition for additional testing, this method was not tried on any of them. From the indications obtained on the scrap material, it appeared that the method might be further developed into one which could be used for production inspection. Since the plastics in the bond have design specifications at -67° F., room temperature, and 160° F., there is the possibility of precooling the material and applying the lacquer at lower temperatures and obtaining surface expansion indications over a greater temperature difference in a lower range. There is also a possibility of obtaining a more sensitive coating thickness of the lacquer by using scientific application or even a lacquer formulae better suited to the specific test conditions.

The method, even if further developed, probably could not be used for in-service inspections because of the surface conditions of the material that would be encountered. Dents, scratches, local initial stress areas, connector gussets, and surface painting would all contribute adverse conditions to its application.

A method of using brittle lacquer for detecting internal flaws in Metalite by mechanical deformation of the object to be inspected was considered.

In conducting this test a method of controlled mechanical deflection was devised. A four inch vice was secured to a horizontal mount. The test strip with a hard maple gripping block on each end was fastened in a vertical position and deflected as a simple cantilever by the use of a lever and turnbuckle arrangement. The deflections to be used were determined while preparing Test Strip 3-3. The strip in its original condition was installed in the apparatus in such a manner that end deflections could be measured. It was then deflected in a series, each successive deflection increasing one-quarter of an inch until one-half inch permanent set was obtained. The mechanical linkage required for each deflection was also recorded. The linkage which had been used to obtain a deflection of eight-tenths of that which gave the permanent set was re-established and used for the test loading. Since only comparative results were desired, the load required to cause the various deflections was not measured. Another strip, the one later used as a control strip, was then installed using the same end blocks and strained to assure the deflection as set up would not exceed the elastic limit of a typical sound strip.

Deflections made by bending the strip twice toward each surface verified the assumption that the deflections established by the equipment would not overstress a sound sample.

The strip used to establish the deflections was then further loaded well past its elastic limit and prepared to use as a test specimen with unknown interior conditions.

The control strip and three test strips were spray-coated with the lacquer and tested—each being deflected twice toward the coated face and twice away from it.

The patterns obtained are shown in Fig. 11.

The results of these experiments indicated that a variation in surface strains was caused by defective interior conditions of the core material or bond on deflected surfaces, and that the brittle lacquer method of detecting this variation would not be applicable for general test procedure. The simplified tests conducted using deflections approaching destructive magnitude on cantilever beam action gave only weak indications. The problem of producing the deflections necessary to locate the required strains over all the surface area of a Metalite sheet or formed shape would make the method impractical even though the principle may be sound.

Blast or Shock Principle

A principle of shock transmissibility was considered. The investigations were conducted to determine how a sudden shock applied to one surface would be transmitted through the Metalite.

The first attempts were made on a test sample secured horizontally in a rigid frame by striking the center of the lower surface a sharp blow with a hammer. The transmitted effects were determined by observing the pattern caused by the induced surface vibrations on a uniformly thin coat of talcum powder which had been applied to the upper surface. It was possible to observe some indications of internal structure. The larger open bond area in Sample 2-1 was detectible, but the small defects and weak bonds in the other samples were not detectable. In experimenting with this method, metal filings and find white sand were also used instead of the talcum powder. The best results were obtained with the sand. Tests with the metal filings were entirely unsuccessful.

Another series of tests based on the same principle were made by securing the test samples over a concussion chamber, 10 in. by 10 in. by 5 in., and discharging an explosion in the chamber. The effects of the explosion on a light uniform covering of sand which had been applied previously to the upper surface of the test plate were analyzed in an attempt to determine the interior condition of the material.

This method provided some successful results on all three of the Series 2 samples. Considerable difficulty was encountered in controlling the impact of the charge and numerous attempts were required to obtain interpretable results. The power and location of the explosion appeared to determine the success of each trial. The best results for each sample could be duplicated by using the same explosive power and location, but each test

sample had a different optimum explosive power and location for the same chamber. Rotating the sample 90° or 180° on the test chamber required redetermining the explosive size and location.

This was one of the few methods which gave any consistent indications of the weakend bond condition suspected to exist in Sample 2-2. It gave three very similar patterns out of the eight charges used in the ideal location under this panel.

The idea appears to have some basis, but because of the danger of overstressing the material and the numerous difficulties encountered in applying the method, it is doubtful that it would be reliable enough to be practicably applied.

Sonic Vibration Principle

Tuning Fork Response

The possibility of inspecting Metallite by studying the effect of sonic vibrations applied to a surface of the material was investigated.

In one method the instrumentation consisted of a bank of four tuning forks mounted on a movable wooden base. The tuning forks were held in a vertical position by mount friction on their sounding stems and could be adjusted to regulate the contact pressure between the sounding stem of each fork and the metal surface to be inspected. The small magnetic transducer was mounted on the opposite end of the base and isolated by a sponge rubber mounting. The oscillating mechanism was held firmly against the metal surface to be inspected by its own

weight and pressure exerted through the rubber mounting. The transducer was excited by an electrical oscillator capable of being tuned to produce oscillations at the natural frequency of the tuning forks used.

The equipment was first placed in position on Sample 1-1 with the entire arrangement clear of the defective area. The amplitude of the induced oscillations was adjusted to a level slightly below that required to obtain response from the tuning forks. A slight increase in the transduced signal picked up by the forks would cause response. With the apparatus operating in this manner, it was moved over the surface of the material to be inspected.

The tuning forks would respond individually as they passed over a defective area where the surface oscillations were increased in magnitude by the resonance of a loose skin area. When the transducer was placed over the defective area, tuning fork response also occurred. By carefully approaching the defective area with the transducer point leading, the boundary of the defect could be fairly well defined.

The device was tested on the Series 2 samples and was successful in locating the defects in Sample 2-1 quite accurately. It gave no indications on Sample 2-2, and although many indications were obtained while in use on Sample 2-3, no definite pattern or void localization could be determined.

The method of mounting the tuning forks was altered to permit them to stand free and to be held damped in sponge rubber, but the results obtainable were not improved. The number of

tuning forks used was reduced and it was found that the results obtained with two forks were just as accurate as those obtained with the original configuration of four.

The operation of the method depends upon an increase in magnitude of the vibration transmitted through the material from the transducer to the sounding stem of a tuning fork. If the frequency of the induced vibration should be the same as the natural frequency of the loose skin area over a void, a maximum response would be obtained and a gain in the amplitude of the transverse vibration occur. The amount of restraint the bond places on the metal surface material influences its damping characteristics and it appears that a method like that attempted could be adapted to give an indication of bond condition. However, since the restraint is through a fairly elastic material---the plastic, into a soft material---the balsa, extreme sensitivity would be required to detect the minor changes which could occur in the small distance between the transducer and the tuning forks.

It was concluded that the method could detect and define only the larger loose skin areas, and since it was much more complicated and equally as difficult to apply as other methods, it was abandoned.

Oscillograph Indications

Three methods were attempted using an oscillograph to determine the vibration pattern which occurred when the surface sheet of Metalite was vibrated at various sonic frequencies.

A series of tests was conducted with the equipment connected as shown in Fig 12. In these tests the intensity of the vibrations was varied by using different transducers and by controlling the electrical input. The oscillator permitted exploration of all frequencies in the audio range but the experimentation was conducted between 20 and 10,000 cycles per second.

The initial tests conducted on Sample 1-1 established the theory that the magnitude of the vibration was greater over an open bond area than it was over well bonded areas. It was noted that the shape of the wave as it appeared on the scope differed depending upon the device which was holding the pick-up, and that when the pick-up was held in the metal triangle holder, the location of the holder in relation to the defective area influenced the shape of the wave form as well as its amplitude. Later in the experiment when this holder was used to scan the larger surfaces, an attempt was made to relate the difference in wave shapes observed to the conditions being encountered, but the attempt was not successful.

An attempt was made to compare the intensity of the surface vibrations existing in Sample 2-1, known to contain defects, with those existing in the control panel. A contour pattern of intensities was established for a given frequency, but a change in frequency changed the pattern, thus introducing the necessity of establishing patterns for the entire range of frequencies to be covered—a task which was considered impracticable. Further experimentation, directed toward establishing certain representative frequencies which could be used in making the desired

comparisons, revealed that the increase in surface vibration intensity desired occurred at a specific frequency for each defect. The type and size of the defect apparently defined the resonant frequency quite definitely, hence it would be impossible to use a small number of standard frequencies to locate all the defects.

An attempt of surface mapping was tried on the samples of Series 2 by passing the carbon pick-up, described as Type 3, along the horizontal grid lines, and recording at one-inch intervals the magnitude of the vibration waves appearing on the scope grid of the oscillograph. A constant electrical input was maintained but the frequency was varied at each point to obtain a maximum reading. This method gave a good indication of the voids in Sample 2-1; it indicated to a limited degree the area of suspected weakened bond in Sample 2-2; but it was erratic in Sample 2-3, Fig. 12a. In general the vibration intensity was about constant for sound areas. It decreased noticeably as the pick-up approached the boundary of a defective area and increased well above sound area values as the pick-up was moved into the defective area.

The method was determined to be effective for locating void areas but was considered unsatisfactory for detecting the other types of defects. The principle was considered function-able and consideration was given to replacing the oscillograph with a Brush recorder or some other means of continuously re-cording the vibration intensity picked up. Then a contour plot could be prepared which would define the defective areas by a system of grid scanning.

In the other method, the scanning probe pick-up was replaced

by a sensitive microphone mounted at the vertex of a pyramidic frustum, the base of which covered one two-inch square grid on the test panel. The preliminary investigation made on Sample 1-1 indicated that results similar to those obtained with the probe pick-ups might be expected. However, experimentation on Series 2 panels did not confirm this expectation.

A plot of surface vibration intensity made using the device failed to indicate a noticeable variation for any of the panels tested. Even grid 7 of Sample 2-1, which is known to be located entirely over an open bond area, registered a reading approximately the same as those obtained on the control panel.

The surface of Sample 5 was explored in an attempt to determine the effect of the thinner surface material on the method, but again it was impossible to obtain significant variation in the readings.

One other variation of the sound propagation principle was investigated briefly with the sonic device before the principle was abandoned. A piece of Metalite was placed directly in front of a 10 in. dynamic speaker and exposed to the sound waves emitted. The opposite side of the sample was explored with the sonic pick-up. The patterns obtained by using the three test samples of Series 2 indicated that the sound conductivity and absorption qualities of the core material, regardless of its condition, distributed the vibrations conducted through the material to cause a uniform vibration intensity on the opposite face. The method of edge support had very little effect upon the variation of intensity. It did change the general level and

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

cause slight uniform reductions near the secured edges.

It was concluded that the sound propagation principle could not be used for the inspection of Metalite since all of the methods attempted failed to detect even maximum variations in the test samples.

Fine Particle Methods

Several attempts were made to determine the effect defective bond areas would have on the surface vibration pattern by using fine particles on the surface.

Sample 1-1 with the small transducer connected in the core-to-surface bond as shown in Fig 19 was supported horizontally and a light uniform covering of fine metal filings scattered over the surface. It was discovered that by changing the frequency of oscillation different movements of the filings would occur and cause characteristic patterns on the surface of the test sample. A frequency of 96 cycles per second caused the metal filings to arrange themselves over the defective area, clearly indicating its boundaries as shown in Fig. 19.

Sample 2-1 with the small transducer connected to the upper aluminum sheet was tested in the same manner but much less movement of the filings occurred and the resulting patterns failed to indicate the defective area. The metal filings were replaced by common sand, a graded silicon powder, and talcum powder. The graded silicon powder gave the best pattern and located the defective area better than any of the other particles.

The method—using the silicon powder—was then applied to the samples of Series 2 and Panel 5. The patterns obtained are shown in Fig. 14.

The method was successful in locating all of the core-to-surface bond defects, but did not show weakened bond areas. It developed a good pattern on Sample 2-3 which could be repeated consistently, indicating that the method had possibilities for mapping defective areas. It was not possible to interpret the type of defect which was causing the patterns to form at the various frequencies but it was concluded that more experience with frequency effect might enable the operator to determine the type of defect being encountered. The method was rather slow because it was necessary to watch for changes in particle movement at all frequencies, and to tune to the optimum frequency when a defective area was indicated. Each defect appeared to have a frequency at which it could best be defined, and in many cases that defect would not appear at other frequencies. The method, like the tapping method, does not insure that all of the defects will be located. It did not indicate defects caused by weakened bond and is more complicated to conduct than the tapping method. Hence, it ~~is~~ was considered inferior to that method.

Another variation of the fine particle method was tried while experimenting with Sample 2-1 for the tests just described. Instead of covering the vibrating surface with a coating of dry fine particles, a one and one-half inch water tight frame was sealed to the surface of the plate with commercial rubber cement. A one-inch deep solution of fine particles of lamp black suspended in

paint thinner was placed in the frame. The sample was vibrated with all the power available but the only patterns obtained were caused by edge restraint. The void edge did not cause any perceptible movement in the adjacent liquid and the method was considered unsatisfactory.

Smoke Convection Patterns

A method of employing smoke circulation to determine the surface vibration pattern of a sheet of Metalite vibrating at sonic frequency was attempted.

The preliminary investigations were conducted by vibrating Sample 1-1 at various frequencies between 20 and 256 cycles per second under the smoke filled glass covered chamber. Both heavy cooled smoke and very light hot smoke were used, and one attempt to use fine silicon powder suspended in the air was made. In each of the attempts, it was possible to observe a change in color or density in the column of air above the defective area, but circulation of the smoke in the chamber could not be detected. The light hot smoke gave the greatest contrast and was used in the testing of the Series 2 samples.

To apply this method to more realistic defects, the three test samples of Series 2 were subjected to this inspection. The samples were secured in a supporting frame, vibrated at various frequencies and amplitudes, with the transducer, Fig. 15. The transducer caused a rarefication of such intensity in the smoke column above the area to which it was attached that it was im-

possible to observe any other variations in the chamber for samples 2-1 and 2-2. A divided or V-shaped pattern was observed when Sample 2-3 was tested with the transducer connected at the centerpoint of an edge. This pattern may have been caused by the large defective area known to exist in the central part of this sample. It was evident that the problem of distributing vibrations would prohibit the application of this method to the larger sheets used in commercial production.

An attempt to apply vibrations by placing the sample in a field of sound waves produced by a 10 inch dynamic speaker also failed to produce distinguishable surface vibration variations on the opposite side.

The investigation indicated that surface vibrations of sufficient amplitude in the lower sonic range would cause a change in appearance of stagnant smoke held in contact with the surface by a closed chamber. It did not, however, prove that the defects in the material sufficiently affected the amplitude of the surface vibration to permit the method to determine the location or even the presence of a defect. Hence, it was considered impracticable and abandoned.

Oil Film Detection

A series of tests were attempted, based on the sonic vibration principle, but using oil film methods of surface scanning to detect variations in the amplitude of surface vibrations.

For these tests induced vibrations were used ranging in

frequency from 20 to 1,500 cycles per second. The test samples of Series 2 were supported horizontally on the adjustable rack shown in Fig. 16, and the dynamic transducer was attached to the center of the upper surface. A pool of light machine oil was then placed on the surface covering all of the interior grid areas and approximately one-half of the area on each of the outer row of grids. An attempt to determine the vibration frequency at which variations in the magnitude of surface vibration occurred was made by observing the behavior of the oil while the induced oscillations were varied through the entire frequency range. The pattern from Sample 2-1 revealed a non-symmetrical arrangement of ripples with marked agitation over the known defective area at frequencies of 200 - 290 and 520 - 600 cycles per second. Increasing the power input caused the oil pool to break consistently in grid 3 and 11. The results indicated that greater agitation occurred directly above the void areas. A symmetrical, almost circular concentric pattern, was observed while testing Sample 2-2, and the oil pool broke in grid 23 when sufficiently strong oscillations were applied. The results could not be interpreted to indicate any particular difference in surface vibrations, and the reason for the consistent breaking of the pool in area 23 could not be determined. Tests on Sample 2-3 caused a non-symmetrical pattern with considerable agitation over grids number 8, 9, 14, and 19. The pool broke consistently over grid 15 or over grid 20 when the transducer power was increased sufficiently.

It was believed that the surface vibration being greater

above defective areas than that above sound areas caused the agitation observed in the oil. The surface vibrations were greater above areas where the surface sheet was not connected to the core material, and those areas were located below the agitated oil. The areas where weakened bond existed were connected to the core material, and surface vibration of those areas remained approximately the same as the vibration over sound areas; hence did not cause observable indications to occur in the oil. A similar test on Sample 5 revealed two horizontal bands of agitation, varying from 1 in. to $1\frac{1}{2}$ in. in width, formed across the surface about one-third the vertical distance between the top and bottom edges. The same pattern appeared when the sample was inverted.

The cause of these areas was not determined. They included considerable sound area as well as the known defective areas. From the results obtained on the samples of Series 2, the agitation was expected only above the defective sections. The method of supporting the plate was different from that used for Samples of Series 2, since Sample 5 was too large to be held by the same frame, but simple support under two edges and point support under each corner of the plate produced similar patterns. The areas were most visible at an induced frequency of 1200 cycles per second, but could be observed at several other lower frequencies.

Small particles of black paint pigments were used in the oil for one test on Sample 5 but they failed to improve the readability of the method.

Other attempts of surface scanning Sample 5 were made by

using droplets of mercury, droplets of SAE No. 50 oil, and spray droplets of mineral oil, but they all failed to locate areas of increased vibration. The path taken by the individual droplets was similar for a constant frequency with varying intensity but varying the frequency at constant intensity caused the droplets to take different paths over the surface. This was interpreted to indicate that the induced vibration frequency affected the path a droplet would follow, but a correlation between the path a droplet took and internal conditions of the material could not be derived.

An additional test was made by securing the water-tight frame, previously used, to Sample 5 and testing the sample with a very thin oil film separated from the metal surface by one-quarter of an inch of water. An attempt to cause the oil film to break over known defective areas by inducing vibrations into the Metalite was unsuccessful. Surface ripples similar to those obtained in the oil film method occurred, but edge effects of the container reduced the area which could be observed, and decreased the detectibility. The method would not detect defects as well as the direct oil pool method and was harder to use; hence, it was abandoned.

The result of these investigations indicated that the methods of oil pooling, water supported thin oil film, and liquid droplet surface scanning, would not sufficiently detect surface vibration variation and could not be used as an inspection procedure.

Surface Contour Methods

One obvious inspection method, that of surface contour inspection, was incorporated in this experiment.

A visual inspection of the panels immediately after they are removed from the bag will sometimes show a blister in the surface material and is one method of locating defective material. As explained in the "Previously Tried Methods of Inspecting Bonds in Metalite" section of this report, the method determines panels which are defective, but does not assure that a panel is free from defects.

It was noted while working with the Metalite that visual inspection should not be directed entirely toward the detection of blisters. Some of the Metalite panels have visible surface patterns, a subdued check, or parallel lines on their surfaces. An area with an entirely different surface pattern, or a smooth surface entirely surrounded by a pattern, could indicate a difference in internal conditions.

A method of measuring surface variations or contour plotting was considered, but the first attempts proved that this method was not applicable. Measurable variations from true flat surface characteristics were encountered in sound material. The specifications permit greater variations in these dimensions than defective bonds would cause.

A method of stressing the bond perpendicular to the surface was devised, and the strain in that direction measured. It was known that the tensile strength perpendicular to the surface of

the Metalite being used (core density 7 - 11 lbs/cu. ft.) should range between 800 and 1200 pounds per square inch, but a definite modulus of elasticity in that direction could not be determined, so instead of using an analytical stress-strain ratio, comparative tests were made.

The first attempts were made by sealing an inverted glass funnel to the surface of sample 2-1 and observing the surface deflection caused by evacuating the funnel. The deflections which occurred were measured by reflecting a light beam from the surface of the material. An attempt to measure these deflections quantitatively using the optics of the aircraft octant was unsuccessful mainly because the deflections which occurred were not symmetrical. A qualitative method using the vacuum principle and a reflected light beam focused on a fixed white background was developed. This method used the control panel to establish an average, and compared the results obtained by subjecting other areas to the same conditions. Again the method was found to be unreliable because of the unknown shapes the deflected surface could take.

The larger vacuum chamber shown in Fig. 16 a was developed, and a mechanical method of measuring a surface point vertical deflection with an Ames Dial was attempted. Comparative deflections could be obtained by this method, but the amount of stress which could be placed on the bond was greatly reduced.

The areas having poor bonds could not be detected, and open bond areas were difficult to locate and would often be undetected.

The material and equipment used by Forest Products Laboratory

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

in conducting a test whose results were indicated by observing surface contours were analyzed. In the tests panels of cycle-weld process Metalite having .012, .020, and .032 inch aluminum surface sheets on one-quarter inch balsa cores were used. They had been exposed for sixteen hours to air pressure of 75 pounds per square inch succeeded by a quick release of pressure, and 24 hours at a pressure of 80 pounds per square inch followed by quick release of pressure. The panels had been exposed to 75 pounds of pressure at 230° F. for three hours and twenty hours in the elevated temperature tests.

The results of the experiment are shown in Table VII.

The surface contour methods failed to reveal poorly bonded areas, and located only the larger unbonded areas in most cases. The detection of defects became more difficult on the samples having thicker face material. Hence, it was concluded that this surface contour principle was not satisfactory for the complete inspection of Metalite, but was adaptable as a supplementary inspection. The visual inspection of the material's surface for blisters as it comes from the autoclave being the most important of the applications.

Soundness Principle

The most widely used method of testing Metalite is the tapping method. This method, when conducted by a trained operator, is simple, efficient, and fairly satisfactory. In order to compare various methods of testing, the writer attempted to develop

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

the technique required to locate defects by this simple method. Two types of tapping hammers were used—a very light commercial tack hammer with a wooden handle, and a light brass headed special hammer with a flexible steel wire shank mounted between the hand grip and the head. In developing this technique, it was found that light tapping gave better sensitivity than heavy blows, that better tone was obtained by using the steel shank type handle, and that rhythm in tapping aided some in determining the exact edges of suspected defects. The tonal characteristics of the room in which the operation was conducted had a definite effect upon the ability of the operator to detect the changes in tone, and as would be suspected, the external noise level also contributed. In practicing, it was discovered that size and shape, as well as method of support of the test specimen, gave different characteristic tones, but that the degree of tonal variation was not materially affected, except in the case of a flat wooden base mounting and a sponge rubber support used while trying to determine the best method of specimen support. All of the simple, solid material point or line supports used gave approximately the same satisfactory variations.

Several of the typical supports tried are shown in Fig. 17.

It was discovered that a basic tonal change occurred as the edge of the plate, a doubler, a change in core material, such as more dense balsa core inlays, tapered core sections, and stiffened edges were approached.

This tonal change is very much like that caused by a defective bond, and when the core plan is unknown, offers difficulty

to the inspector. This change is encountered at critical stations in the material since stiffeners, doublers, and inlays are inserted to distribute high stresses, which are expected in those areas. Hence, it is very important to determine accurately the bond conditions in those sections.

The results which may be obtained by this method are illustrated in Fig. 15 which pictures an actual defective Metalite aircraft door and a plot of the open bond or defective areas beneath its surface sheet.

The writer believes the tapping technique developed while working on this project enabled him to determine the internal condition of Metalite material better than any of the other methods attempted during the investigation. The reliability of this method is limited because it is impossible to determine with certainty that all the smaller defects are located, and to locate areas of weakened bond where intimate contact between the face and core material exists through the presence of hardened but weak bond plastic.

Good results in locating defects were obtained by tapping Metalite with a silver coin. A quarter was preferred by the writer because of its size and weight. The "feel" and tonal quality produced by the coin compared very favorably with those obtained using the special hammer, and were definitely better than those given by the tack hammer.

Some additional experimentation involving the soundness principle was conducted by dropping a small steel ball a given distance onto the surface and observing the height of its rebound. Quali-

tative comparison of surface areas somewhere could be obtained. The defective area in Sample 2-1 was detectable and fair results were obtained from Sample 2-3, but Sample 2-2 could not be analyzed. Two of the defects in Sample 5 were located, but the one-inch area caused a response just like that obtained from a sound area. It was concluded that this method as tested was not any more sensitive than the tapping method, and since it was slower and harder to use, it was considered inferior.

It appeared to respond to solid areas quite well and it might be refined into a more sensitive method which could detect weak bonds. It does give a measurable quantitative indication by the height of bounce that occurs, whereas the tapping method depends upon the inspector's ability to detect tonal changes.

RESULTS

The ideal of discovering a principle on which a simple test to determine the condition of the bond adhesion and core condition inside a flat sheet of Metalite could be based was not achieved.

The detailed results obtained in the tests conducted during this investigation are given in the respective sections of the "Methods of Flaw Detection" section of this report.

A summary of the qualitative general results obtained are expressed in table form on the following page.

Only two of the seven kinds of imperfections or flaws itemized in the Introduction could be detected by any one method of inspection. By using a combination of methods only four of the seven could be detected, and the location of a defect in core material strength or density was doubtful even then. The weak joints in core material, difference in bond strength on opposite sides of the core, and variance in bond strength over the surface sheet could not be detected by any of the methods discussed in the report.

Comparison of Tests Attempted

The tabulation expresses the extent to which each of the various tests was able to locate the defects and to define similar defects in the test samples. The samples of Series 2 offered the best comparison since they contained three of the most representative defects encountered and were tested by most of the methods.

The code used in tabulating these tests is:

I All known defects located--positive indications

i Some indications obtained

D Defective Material

ND Sound Material--no defects

e Indications occured where expected

u Location of indic tions unexplainable

Type of Indication

1 Clear positive indication well defined

2 Positive indication--boundary not distinct

3 Weak indication

4 Doubtful indication

5 Indication occurred but without pattern

6 Inconsistent indications

7 Indications occurred but evidently from causes other than the defects being tested for

Classification of Test

U — The test could be used as conducted in experiment

P — The method used in experiment could possibily be further refined and adapted to commercial use

LV — The method capable of being used under certain conditions--would be of limited value commercially

IP — The method considered to be impractical

NA — The method considered not applicable

? — The method questionable--results not reliable

Tabulation

Tests Attempted	Sample Used 1-1	1-2	2-1	2-2	2-3	5	Result
Heat Radiation: Surface Temperature		Ie2	ie2	N	Ie5		LV
Smoke Pattern			N				NA
Thermal Conductivity: Total Panel			Du	Du	Du		NA
Smoke Pattern			ie2	N	Ie4		IP
Frost			Ie2	ie3	iu5		IP
Condensation			Ie2	iu6			IP
Heat Absorption		Not Applicable					NA
Brittle Lacquer: Vibration	iu6	iu5					NA
Heat			Special Samples Ie2	Ie2			
Deflection			Test Strips Ie2	Iu3	Ie2		IP
Shock or Impact: Hammer			ie3	N	iu5	N	IP
Explosion			Ie2	ie3	ie3		IP
Tuning Fork	Ie1		Ie1	N	iu5	ie4	LV

Test Tabulation (Cont.)

Test Attempted	Sample Used						
	1-1	1-2	2-1	2-2	2-3	5	Result
Oscillograph Detection Mechanical	Iel	Iel	Ie2	ie3	iu6	ie3	P- LV
Audio	Ie3	N	N	N	N	N	NA
Sound Wave Field			N	N	N		NA
Fine Particles Dry particles	Iel	Ie3	Iel	N	ie2	N	LV
Particles in Liquid			N			N	NA
Sound Propagation	Ie2	N	Ie2	N	ie4	ie4	P
Smoke Convection (Vibrating Surface)	Ie2	Ie4	iu7	iu7	ie4		IP
Oil Film Pool on surface			Ie2	iu4	ie5	iu7	?
Suspended on water						iu3	?
Droplets						iu7	NA
Surface Contour Visual observation	Iel	Ie2	ie3	N	N	N	LV
Light Reflection			ie6	iu6	iu6		?
Ames Dial (mechanical)			Ie2	N	ie3	N	LV
Soundness Tapping	Iel	Iel	Iel	ie3	ie6	ie4	U
Bouncing Ball		Ie2	Iel	N	ie2	ie3	U

COMPARISON AND DISCUSSION

The investigation did not reveal any one basic principle that appeared to be able to detect all of the imperfections or flaws which might occur in Metalite. It did establish the fact that at least five of the principles could be used to explore the internal condition of the material. These were:

1. Heat Radiation
2. Thermal Conductivity
3. Blast or Shock Principle
4. Surface Response to Sonic Vibrations
5. Soundness Principle

Of these the Soundness Principle, through the application of the tapping method, proved to be the most versatile and reliable. It was dependent upon the skill of the operator and was unable to locate areas of weakened bond, sections of split core material, or areas of no bond between the surface skin and the core if intimate contact remained, but it was reliable in locating the type of defect which occurred most frequently--the open bond between surface and core--and was fast and easy to apply. It was used during the experimentation as a standard or basis on which to judge the other methods.

One method of applying the Heat Conductivity Principle appeared to be worthy of further consideration because it showed possibilities of being able to detect areas of weakened bond as well as the defects in surface-to-core bonds. That method was

the surface temperature scanning method, and the only reason the method was not investigated further was the inavailability of the necessary sensitive surface scanning equipment. It is believed that this basic idea might be developed into a method that would be better than the tapping method for flat sheets of the material. Curved panels would not offer great difficulties, but tapered sections might restrict its application.

The Tuning Fork Detection Method of the Sonic Vibrations Principle could detect the same type of defects as the tapping method, but was more complicated to apply, and slower. It was also more dependent upon vibration frequency and would of necessity require controlled conditions of application, but was considered to rank third in importance.

The next in order of importance was the Shock Principle applied through the Blast Method, but due to the limitations explained earlier, it was not considered further even though it occasionally turned up excellent indications.

The Fine Particles vibrating on the surface of the material were found to be capable of detecting voids and defining their boundaries when sufficient amplitude of vibration could be induced into the surface material at the proper frequency. The problem of determining that frequency placed this method as the most undesirable of the principles because it was a time consuming tedious task.

Quantitative results could not be determined in most of the trials and even in the case of the heat principles where attempts were made to use quantitative analysis, the results

indicated that comparative methods would be better.

The methods investigated all failed to determine the quality of the bonds, hence it appears that the assurance afforded by rigid quality control, similar to that described in Ref. 6, excercised during the manufacturing process will have to be relied upon until better inspection methods can be developed.

CONCLUSIONS AND RECOMMENDATIONS

1. A satisfactory means to determine the quality of a bonded structure was not discovered. The most accurate check of quality can be obtained by extracting test specimens from the waste areas of a finished panel and testing them to failure—the principle now used in quality control procedure.

2. The Soundness Principle applied by tapping is the most practical method to use for locating the common surface-to-core bond defects.

3. A method of exposing heated bonds to sudden pressure drop and observing the surface contour of the material is the most practical method to use for locating weak surface-to-core bonds.

4. A non-destructive test using the Button-Pull Method could be developed to assure a minimum bond strength between the surface and core materials.

5. Principles involving the homogeneous and uniform characteristics of a material are applicable to some inspection methods for use on Metalite panels such as were used for these investigations. However, the application of the same principles to the inspection of fabricated Metalite parts would not be successful. The presence of inserts, doublers, reinforcements, and variances in core thickness and density would limit their effectiveness. It is considered impracticable to attempt the development of a general inspection method based entirely on these principles.

6. The Soundness Principle appears to be the most promising in locating core-to-surface defects, and a penetrating radiation or supersonic shadowgraph principle appears best to detect core flaws or imperfections.

Since no one method was discovered which would indicate the internal conditions existing in the Metalite and combinations of the methods attempted failed to reveal all of the possible defects which might occur, a system of tests combined with a rigid process control is recommended. This system should employ:

1. Carefully controlled process specifications.
2. Quality control of the materials used.
3. A schedule of destructive tests to be conducted on margin material or companion samples distributed throughout the production cycle.
4. A visual inspection for defect indications on the surface of the heated material after exposure to a sudden drop in pressure.
5. A systematic tapping inspection.
6. A button-pull test on any area suspected to contain a defect or expected to be subjected to high stress concentrations.

APPENDIX A

Methods of Bonding Used in the Fabrication of Metalite

The older of the two processes now used to produce Metalite is the Cycleweld Process. This process incorporates a high-temperature-setting modified thermosetting priming resin, Cycleweld C-3, which is a product of the Chrysler Corporation, sprayed directly onto the clean aluminum surface, air dried, and then cured at a bond-line temperature of 260° F. - 270° F. under 60 - 90 psi pressure for one hour. The primed aluminum is bonded to the balsa core with a high-temperature-setting phenolic resin, Durez 13297, a product of the Durez Plastic and Chemical Company, by curing at 230° F. - 250° F. under 60 - 90 psi pressure for one hour in an autoclave. In this process the liquid Durez is applied to the metal parts only and allowed to air dry. The wood core is sized with a very light application of a different type resin, to prevent core swelling, and no further adhesive is applied. All of the parts in the assembly stage are tack free and have a minimum of moisture present to affect the bond condition. The process produces a glue line which weighs about 0.1 pound per square foot of panel area.

The other process now in use is called the Redux Process. It makes use of a high-temperature-setting liquid resin and thermoplastic powder. In the process the liquid, Redux, which is a product of the Resinous Products and Chemical Company, is applied to the clean aluminum surface. While the liquid is

still wet the surface is coated with Redux powder and permitted to air dry. After assembly the panel is cured by the blanket process in an autoclave at 250° F. - 260° F. for 30 minutes to one hour under 60 - 70 psi pressure.

One of the most important steps in the fabrication of the Metalite and one that contributes much toward the elimination of defects in the bonds is that of obtaining the "clean" surface to which the bonding material is applied. Methods such as alkaline degreasing and the light acid etch have given way to a sodium metasilicate degreasing bath followed by a chromic acid dip. The variables such as cleaning baths' temperature and concentrations, times of immersion in the baths, and times of rinse, and methods of drying are carefully controlled.

Ref. 1 and 11.

APPENDIX B

The Effect of Defects on Strength of Metalite

It was expected that poor bonds which would reduce the tensile strength between the facing and core material would also reduce the compressive strength of a panel. An exact relationship between the bond tensile strength and the edgewise compressive strength of the panel has not been established.

In tests conducted by the Forest Products Laboratory, Ref. 7, two tests were used to evaluate the effect of defects in sandwich construction, the edgewise compressive test and the flatwise tension test. The edgewise compression tests were made on flat and curved panels using the test methods described in Ref. 8. In the test samples the poor bonds were produced by using the regular fabrication process except a very light spread of the secondary adhesive, one-tenth of the amount normally used, was applied in a single application just before curing.

The unbonded areas in the flat panels for compression tests were 1/2, 3/4, and 1 inch in diameter and in the core-to-surface bond on one side of the test panel only. The unbonded areas were produced by tape-masking the area before applying the adhesive thereby leaving an area void of adhesive for the fabrication.

The tests on flat panels revealed that the specimens with poor bond had only 22.5% the core-to-surface bond strength of a sound panel and in flat edgewise compression an average of 12

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

specimens indicated the compressive strength to be reduced only 10% by this weakened bond. It was also noted that only three of the twelve failures occurred in the bond. The specimens having the two smaller areas of no bond failed to show any decrease in edgewise compressive strength and the one with the one-inch open bond area indicated a decrease of only five percent of the normal strength. All the failures that occurred while testing samples containing 3/4-inch and one-inch void areas occurred in the bonds.

APPENDIX C

The Production of Balsa Cores Used in Metalite

Balsa as an end grain core for Metalite poses many questions regarding processing and durability. Its known inherent susceptibility to moisture absorption and the dimensional changes which accompany a change in moisture content influence the applications, the fabrication processes, the adhesives which may be used, the inspection methods required, and the durability of the finished Metalite. The particular use of balsa as an end-grain core in Metalite limits the moisture absorption in the finished product by exposing only flat grained surfaces at the panel edges and sealing the end-grain surfaces by metal facings. The moisture content stability required in the manufacturing process is accomplished by humidification in production areas and by using fabrication techniques which permit the contraction and expansion of the core panels to be held below an acceptable minimum. Stabilization by means of impregnation with dimethtolurea or commercial water repellents increases the core weight and costs involved more than the stability gained justifies and is not used.

The core moisture content affects bond strength by contributing additional internal pressure during the curing process, especially when the curing temperatures are above 212° F. An optimum core moisture content of 6% - 12 % was determined and is maintained during the production.

Other physical-mechanical properties of balsa which influence

See back of page 66 in this carbon copy for page 64

bonding techniques are used. Balsa sticks of the requisite density group are selected and dressed on opposite sides prior to edge-glueing into planks approximately 2¼ inches wide. The adhesive used is a room-temperature-setting resorcinol type which conforms to Joint Army Navy specification JAN-A-397. The planks are dressed by planing both surfaces and then laminated to make a core bolt of the desired height. End-grain core sections of proper thickness are band-sawed from the bolt. Each section is carefully inspected for internal defects that have not been observed when the balsa was in stick form. Fig. 19 shows a typical core section fabricated and sanded ready for installing in a panel. Acceptable core sections are edge-glued to form larger core panels if required. The thickness tolerance for drum-sanded cores is plus or minus 0.005 inches. The finished core panels are stored under controlled humidity conditions to assure the necessary 6% - 12 % moisture content when used.

The cores are available for visual inspection, flexing and soundness testing as they are applied to the metal surfaces, hence the initial condition of the core is definitely known at this stage of assembly.

Ref. 12.

Requirements for Balsa Lumber (Ochroma lagopus)

Description	Specification Criteria
Moisture Content	Material shall be measured to contain not more than 15 nor less than 5 percent in individual pieces based on oven-dry weight. Average moisture content of individual lots shall not exceed 12 percent.
Density	Permitted range is 6 to 1[illegible] lbs./cu.ft. including moisture. Density shall be as specified in the contract or order.
Fiber Structure	No band of short fiber shall be more than 1/8 inch wide measured in a radial direction, and adjacent bands shall not be closer than 1½ inches in a radial direction.
Decay, Pith, Shake, Compression Failures, and Water Heart	Not permitted.
Seasoning Defects	Collapse, Honeycomb, Case Hardening, Kiln Burn, and Crook, Warp or Twist are not permitted.
Mineral Stains	Permitted if not associated with decay.
Blue Stains	Mild blue stains permitted.
Knots	Sound knots permitted up to 1½ inches in diameter. Minimum spacing 2 inches.
Bird's Eye and Pin Knot Clusters	Occasional areas permitted.
Checks or Splits (surface)	One permitted per surface if not more than 1/4 inch deep and 1/64 inch wide. No limit on length.
Grain Slope	A slope not steeper than 1 in [illegible] is permissible.
Worm Holes	Scattered pin worm holes acceptable.

The above requirements have been condensed from the Bureau of Aeronautics Specification [illegible] and C. V. A. Specification [illegible].

production have been considered and the effect of their variations were determined in order to establish the basic standards required.

In general the material specifications set out in Ref. 10 are presented in tabular form as a part of this Appendix.

Short fiber lumber would produce weak transverse tensile strength if used as a core material. A scratch test on the transverse ends of each stick is used to detect this characteristic. Material which tears out and exhibits a corky or brash rupture under slight pressure is classified as short fiber, while material resisting breakage is classified as acceptable long fiber.

Another characteristic of great importance is the density. Volume-Weight measurement methods are used to determine density at the source of procurement and a simple flotation method is used at the processing plant. Very little balsa with a density below seven pounds per cubic foot is used because it contains large amounts of low-strength short fibers. The standard density ranges established by Ref. 10 are: 7 - 9 lb./cu. ft., 9 - 11 lb./cu. ft., 11 - 14 lb./cu. ft. and 14 - 18 lb./cu. ft.

Tests to determine the effect of the bond curing temperatures and elevated surface temperatures on the balsa demonstrated that balsa is capable of withstanding exposure to high temperatures for short periods. Subsequent comparative tests have shown that the bonding adhesives are generally the limiting factor when extreme conditions of -75° F. or above 250° F. are encountered.

In the fabricating conventional woodworking equipment and

REFERENCES AND BIBLIOGRAPHY

1. Experiences of an Aircraft Manufacturer With Sandwich Material, Gibbons, H. B., SAE Quarterly Transactions, July 1947, Vol. 1 No. 3.

2. Acoustic Image Inspection Method (Contract Summary Report), Research Dept. Sperry Products, Inc., Danbury, Connecticut, October 15, 1948.

3. Acoustic Image Inspection Method (Supersonic Shadowgraph) Research Dept. Sperry Products, Inc., Danbury, Connecticut, May 12, 1949.

4. Inspection of Metalite Panels with the use of the Brush Hypersonic Analyzer, Hamburg, H. F. and Gibbons, H. B., Report No. A-3761, Chance Vought Aircraft Corp., Dallas, Texas, August 5, 1946.

5. Investigation of Methods of Inspecting Bonds Between Cores and Faces of Sandwich Panels of the Aircraft Type, Heebink, B. G., Mohaupt, A. A., Report No. 1569, Forest Products Laboratory, U. S. Dept. of Agriculture, Madison, Wisconsin, September 1947.

6. Quality Control of Aircraft Sandwich Materials, Epstein, Herbert B., Aero Digest (p-38), June, 1950.

7. Effect of Defects on Strength of Aircraft-Type Sandwich Panels, Heebink, B. G., and Mohaupt, A. A., Report No. 1809, Forest Products Laboratory, U. S. Dept. of Agriculture, September, 1949.

8. Methods for Conducting Mechanical Tests of Sandwich Construction at Normal Temperatures, Progress Report Author not listed, Report No. 1556, Forest Products Laboratory, U. S. Department of Agriculture, Revised October, 1948.

9. Test Methods of the Structural and Mechanical Test Branch, Part I, Vol. I. Advisory Report on Test Methods of the Materials Laboratory Engineering Division, Air Technical Service Command, Wright Field, Dayton, Ohio, September 5, 1945.

10. General Specification for Inspection of Material - Appendix X, Specification No. 3939, issued by the U. S. Department of the Navy. (Chance Vought Aircraft Material Specification No. 541 superseded).

11. Fabrication of Light Weight Sandwich Panels of the Aircraft Type, Heebink, B. G., Mohaupt, A. A., and Kunzweiler, J. J., Report No. 1574, Forest Products Laboratory, U. S. Department of Agriculture, June, 1947.

12. Balsa Wood as an End-Grain Core Material in Sandwich Construction, Reid, David G., Chance Vought Aircraft, Department of Publications. Not dated or numbered.

13. Durability Tests of Metalite Sandwich Construction, Reid, David G., ASTM Bulletin No. 164, February, 1950.

SURFACE COOLING RATE -- Sample 1-2

Thermometer Located Over Solid Area		Thermometer Located Over Void Area	
Time	Temperature	Time	Temperature
10:13	127 °F.	09:36	128 °F.
:15	122	:38	120
:17	117	:40	111
:19	109	:42	107
:21	105	:44	102
:23	101	:46	98
:25	97	:--	--
12 Min.	30 °F.	10 Min.	30 °F.
Rate 2.5 °/ Min.		Rate 3.0 °/ Min.	

Table I

SURFACE COOLING RATE -- Sample 2-1

Grid Point	1	13	7	19	10	8	11
Time order							
13:42 1-11 14:14 11-1	119.0 114.0	118.0 113.0	119.0 113.0	117.0 115.5	116.0 116.5	116.0 117.0	115.0 118.0
Average	116.5	115.5	116.0	116.3	116.3	116.5	116.5
13:46 1-11 14:18 11-1	108.0 103.0	107.5 103.0	105.0 99.0	106.5 105.0	106.0 106.0	103.4 103.3	103.0 103.0
Average	105.5	105.7	102.0	105.8	106.0	103.3	103.0
13:50 1-11 14:22 11-1	98.7 96.0	98.0 96.0	94.0 95.0	97.0 98.0	96.5 98.5	93.0 96.7	94.0 96.5
Average	97.3	97.0	94.5	97.5	97.5	94.8	96.5
Average Degrees cooled in 8 min.	19.2	18.5	21.5	18.8	18.8	21.7	20.0
Average Cooling Rate	2.40	2.31	2.69	2.35	2.35	2.71	2.50

Table II

SURFACE COOLING RATE -- Sample 2-2

Grid Point	1	13	7	19	10	8	11
Time Order							
15:02 1-11 15:35 11-1	114.0- 106.0	112.5 107.3	114.0 107.0	113.5 107.0	111.5 110.0	111.0 110.0	110.0 110.5
Average	110.0	109.9	110.5	110.5	110.7	110.5	110.3
15:06 1-11 15:39 11-1	101.5 95.0	99.0 92.5	101.8 94.0	101.0 94.5	99.5 98.0	98.5 98.0	98.0 98.0
Average	98.3	95.8	97.9	97.8	98.8	98.3	98.0
15:10 1-11 15:41 11-1	92.5 88.0	90.3 86.3	92.5 87.0	92.0 87.5	91.0 90.0	90.0 90.0	90.5 90.5
Average	90.2	88.3	89.8	89.8	90.5	90.0	90.5
Average Degrees Cooled in 8 Min.	19.8	21.6	20.7	20.5	20.2	20.5	19.8
Average Cooling Rate °/ Min.	2.48	2.70	2.59	2.56	2.52	2.56	2.48

Table III

SURFACE COOLING RATE -- Sample 2-3

Grid Point / Time Order	1	13	7	19	10	8	11
16:12 1-11 16:53 11-1	120.8 119.0	120.0 119.0	120.0 120.0	119.5 119.8	120.0 120.5	119.0 120.8	118.8 121.3
Average	119.9	119.5	120.0	119.7	120.3	119.9	120.0
16:16 1-11 16:57 11-1	110.0 109.5	112.5 111.8	112.0 112.5	111.0 112.5	110.3 110.0	109.5 112.5	109.5 110.3
Average	109.8	112.2	112.3	111.7	110.1	111.0	109.9
16:20 1-11 17:01 11-1	103.0 103.0	107.0 106.0	105.8 106.5	104.5 107.0	102.0 102.5	103.0 106.5	102.0 102.5
Average	103.0	106.5	106.2	105.8	102.2	105.3	102.2
Average Degrees Cooled in 8 Min.	16.9	13.0	13.8	13.9	18.1	14.6	17.8
Average Cooling Rate °/ Min.	2.11	1.63	1.73	1.74	2.26	1.83	2.23

Table IV

TEMPERATURE OF AIR IN 500 cu. in. UPPER CHAMBER CLOSED

Exposure Time	Control Panel	Sample 2-1	Sample 2-2	Sample 2-3
Initial	73 °F.	71 °F.	72.5 °F.	71.0 °F.
5 Min.	79.5	81.0	80.0	79.0
10 Min.	89.0	91.0	89.0	88.0
15 Min.	97.0	97.5	96.5	95.3
20 Min.	101.0	102.5	101.5	100.5
Temperature Increase in 20 Minutes	28.0	31.5	29.0	29.5

Table V

Oven Temperature 150°F.

Room Temperature 71°F.

TIME FOR 10° TEMPERATURE RISE IN 500 cu. in. UPPER CHAMBER

Sample	Control Panel	Sample 2-1	Sample 2-2	Sample 2-3
Initial Temperature in Upper Chamber	73.0 °F	71.0 °F	72.5 °F	71.0 °F
Time Required to Increase Initial Temperature 10°F	7.0 min	5.0 min.	5.5 min	7.0 min
" 20°	11.5	10.0	11.0	11.0
" 30°	21.5	18.0	20.5	20.0

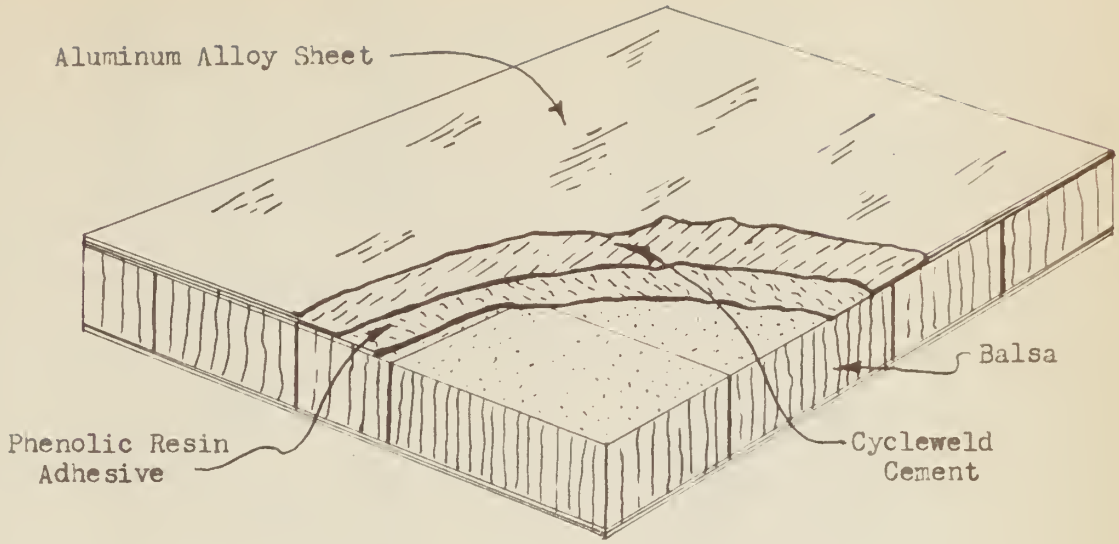
Table VI

Thickness of Aluminum Face	Character of bond at defective area	Diameters of Defective Areas located by:				
		Tapping	16 hours at 75 psi	24 hours at 80 psi	3 hours at 220° F. 75 psi	21 hours at 230° F. 75 psi
Inch		Inch	Inch	Inch		
0.012	No glue	2, 1-1/4, 3/4 & 1/2	2 & 1-1/4	2, 1-1/4, 3/4, & 1/2	Large blister included 2- & 1-1/4 area. 3/4 & 1/2 area blistered	Large blister including 2 & 1-1/4 3/4 & 1/2 area blistered
0.012	Poor	None	None	None	None	None
0.020	No glue	2	2 & 1-1/4	2, 1-1/4 & 3/4	Same as 1 above	Same as 1 above
0.020	Poor	None	None	None	None	None
0.032	No glue	2	2	2 & 1-1/4	2- and 1-1/4 blister also on back side 2" area	2- and 1-1/4 area blister on back covering practically all areas
0.032	Poor	None	None	None	None	None

Results of Inspection of Small Defective Panels by Tapping, Internal Pressure, and a Combination of Internal Pressure and Heat

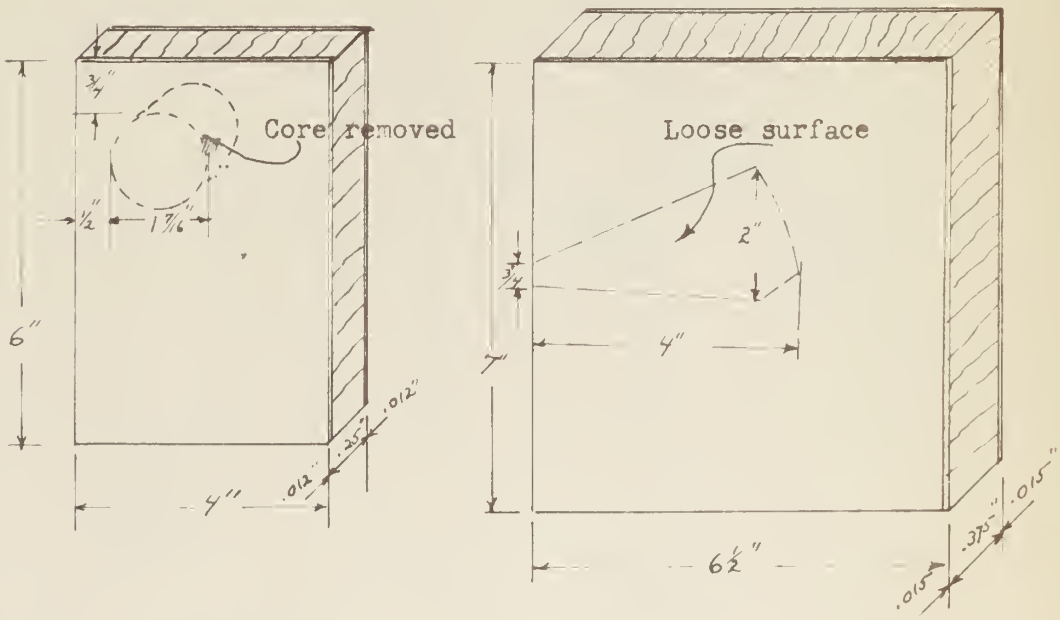
Taken from Ref. 5

Table VII



ARRANGEMENT OF BALSA CORE IN METALITE SANDWICH MATERIAL

Fig. 1



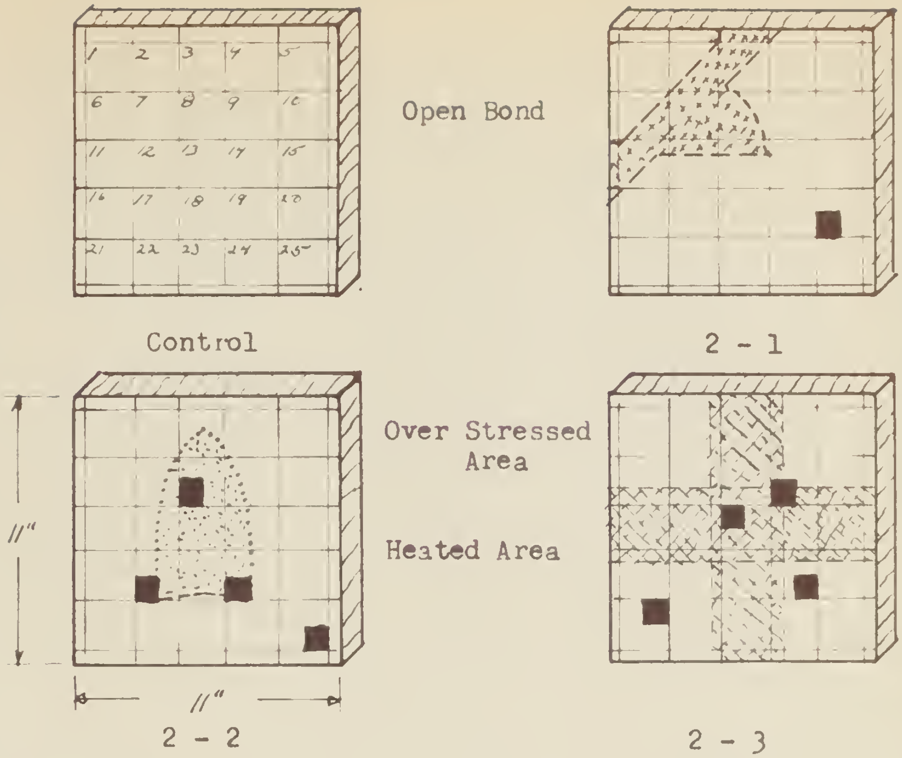
Sample 1-1

Sample 1-2

METALITE TEST SAMPLES

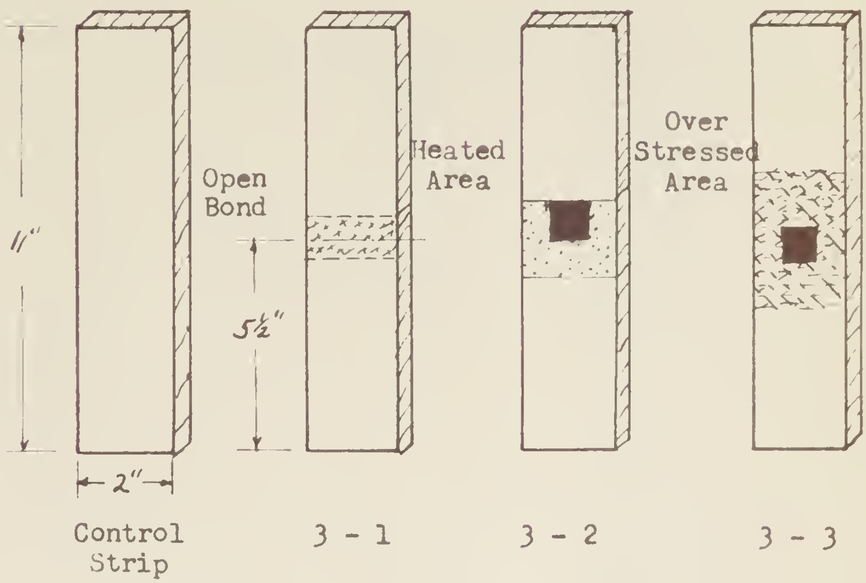
SERIES 1

Fig. 2



SERIES 2 TEST SAMPLES

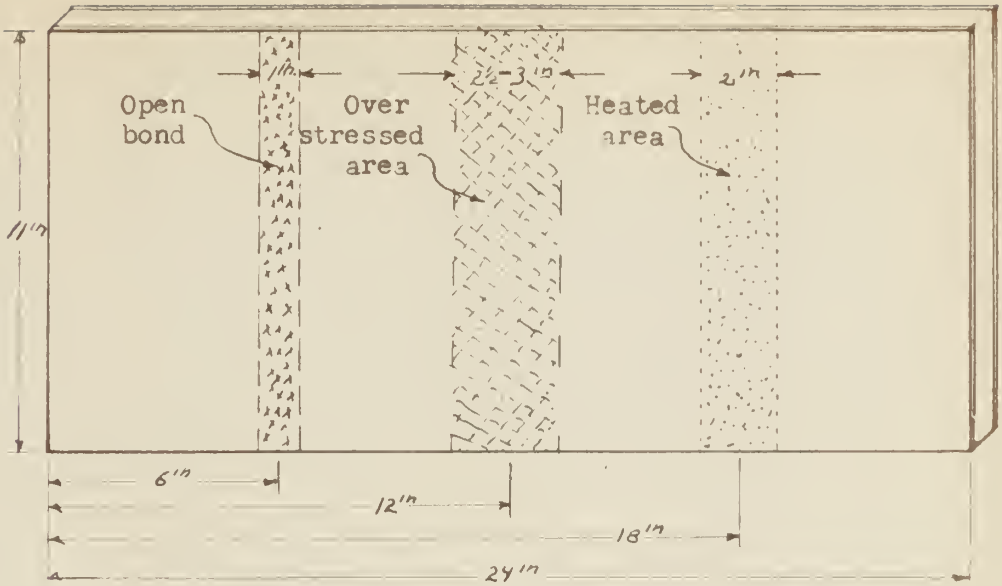
Fig. 3



SERIES 3 TEST SAMPLES

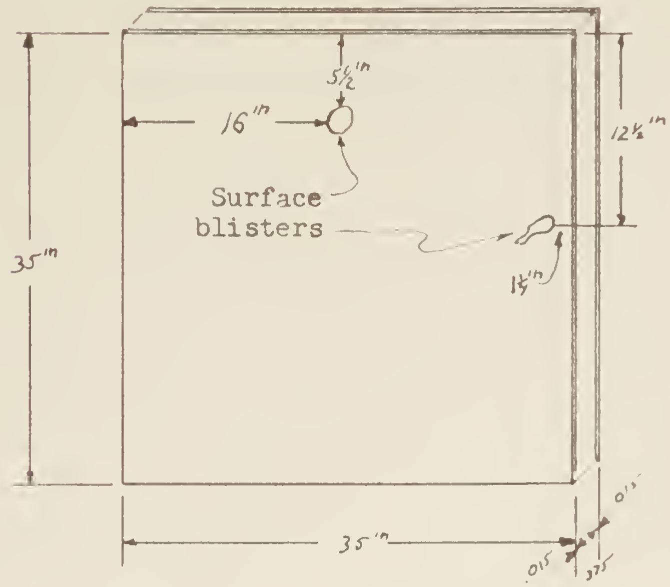
Fig. 4

■ Test Biscuits removed from these areas for final bond tension testing.



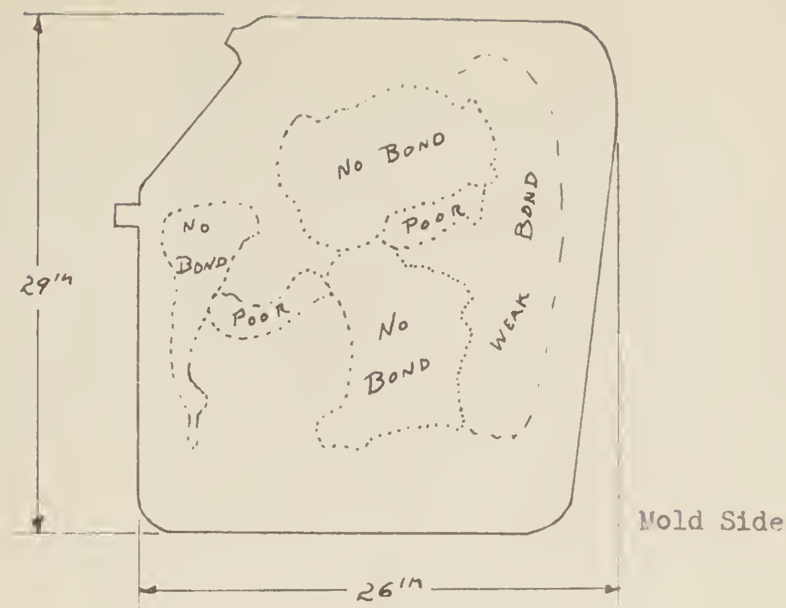
SAMPLE 4 - 1

Fig. 5



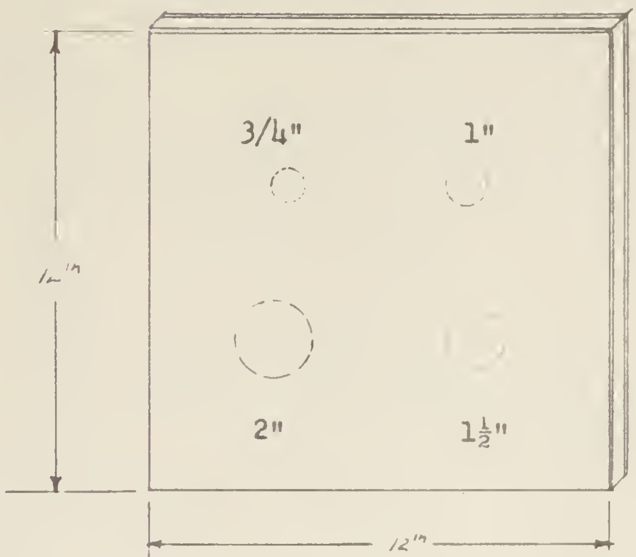
SAMPLE 4 - 2

Fig. 6



AIRCRAFT DOOR

Sample 4-3 Fig. 6a



Test Sample 5

Fig. 7

Temperature Averages

1 121.0 °F

3 119.6

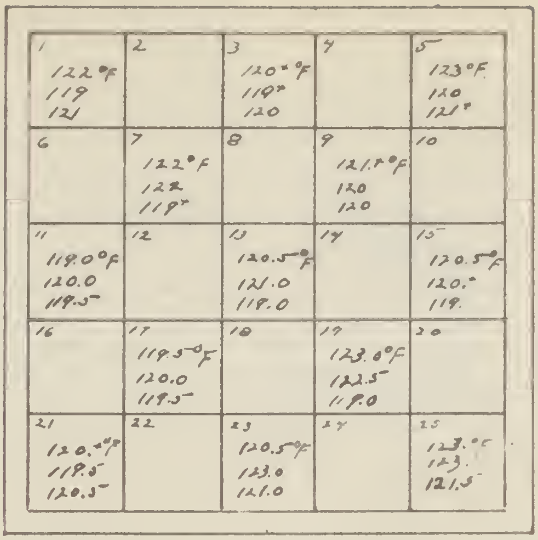
7 119.5

11 119.5

13 119.8

17 119.7

21 120.0



Temperature Averages °F

5 121.3

9 120.3

15 119.8

19 121.5

23 121.5

25 122.5

HEAT ABSORPTION OF CONTROL PANEL AS

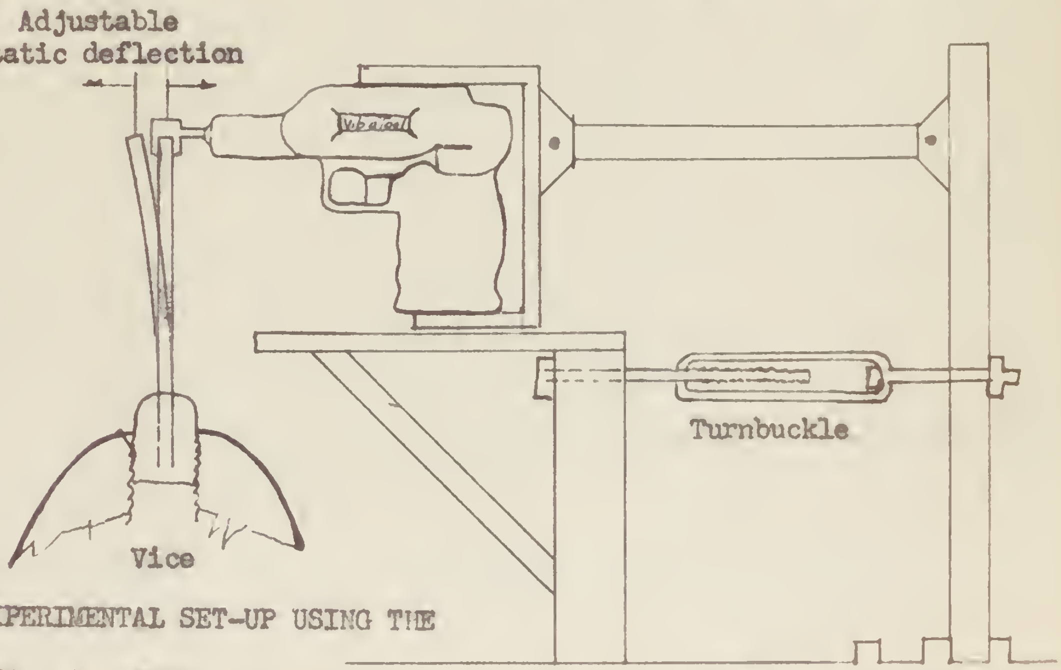
INDICATED BY SURFACE TEMPERATURE

Fig. 8

Average of Three tests:
Maximum variation 3.5°

Maximum variation 3.0°
Sample 2-1

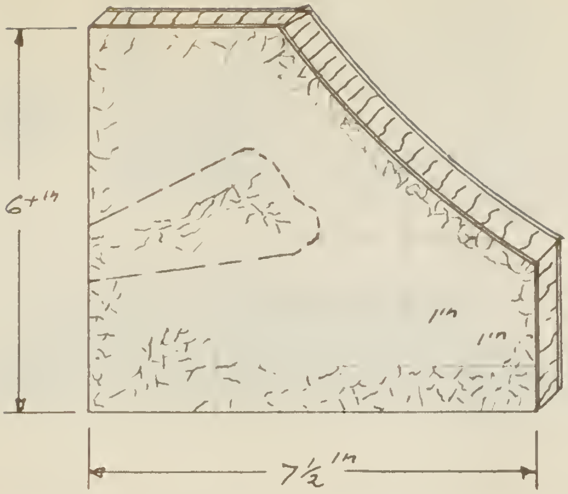
Sample 2-2 and 2-3 tested in one run only -- results not shown.



EXPERIMENTAL SET-UP USING THE

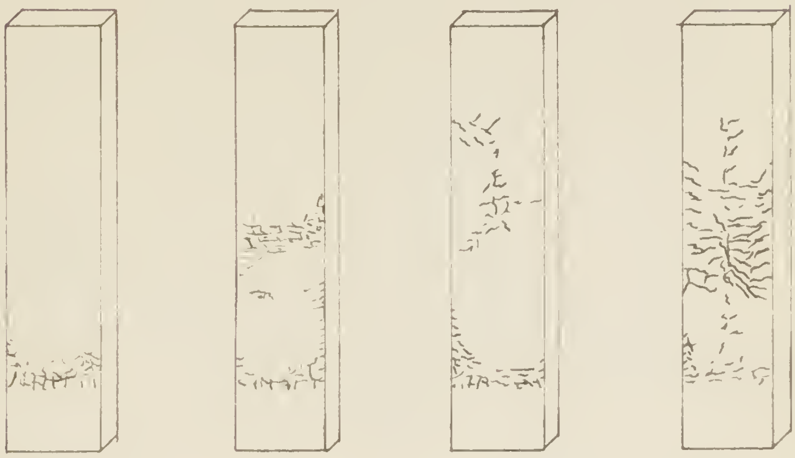
VIB - A - TOOL

Fig. 9



SCRAP MATERIAL SAMPLE USED IN BRITTLE LACQUER TEST *

Fig 10

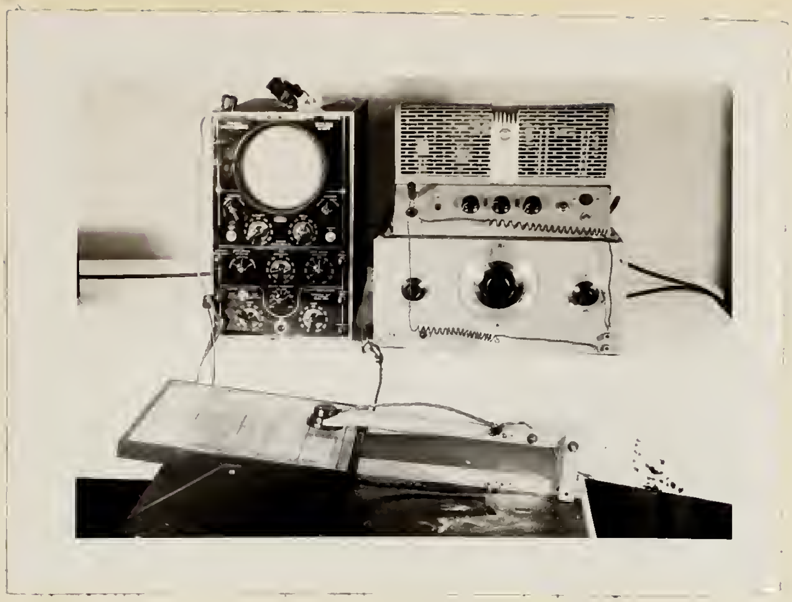


Control 3-1 3-2 3-3

BRITTLE LACQUER PATTERNS ON SERIES 3 TEST SAMPLES *

Fig. 11

* The indications in Fig.'s above show the general location of early checking. Distinct lines or patterns were not obtained.



EQUIPMENT ARRANGEMENT FOR OSCILLOGRAPH METHOD TESTS

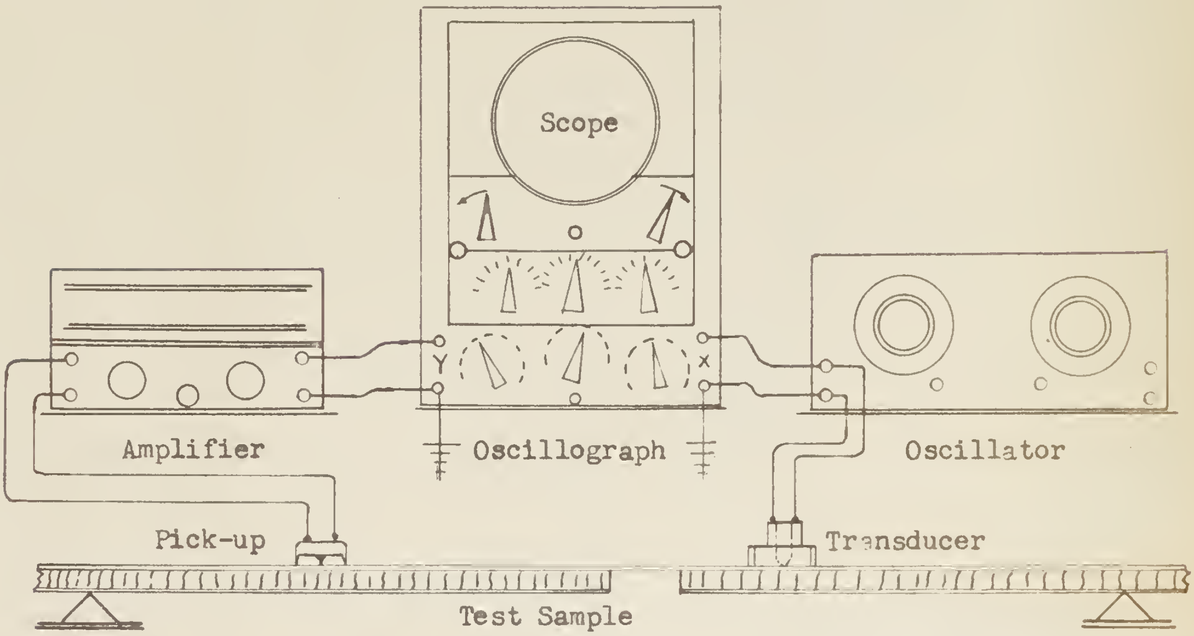


DIAGRAM OF SONIC VIBRATION TESTING EQUIPMENT
(Oscillograph method)

Fig. 12

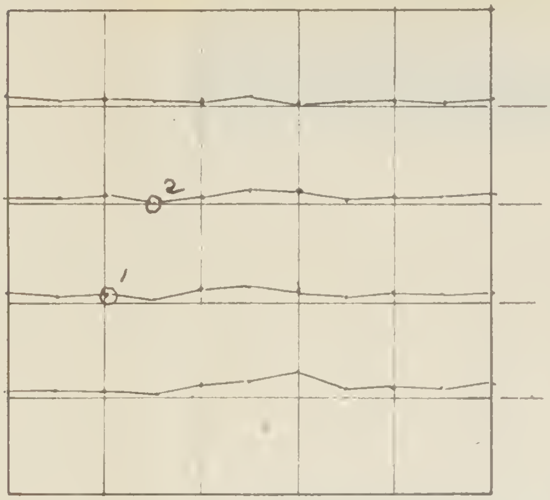
Magnitude of Scope Waves

Series 2 Samples

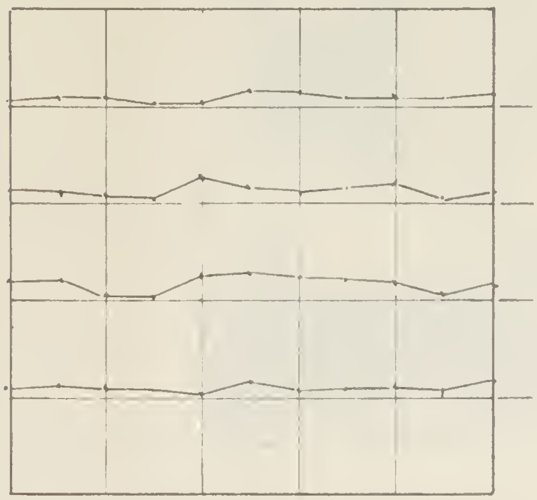
Vibration Wave variation plotted vertically from 1 in. Reference Lines

1 in. Reference Lines also grid lines

Sample 2-1

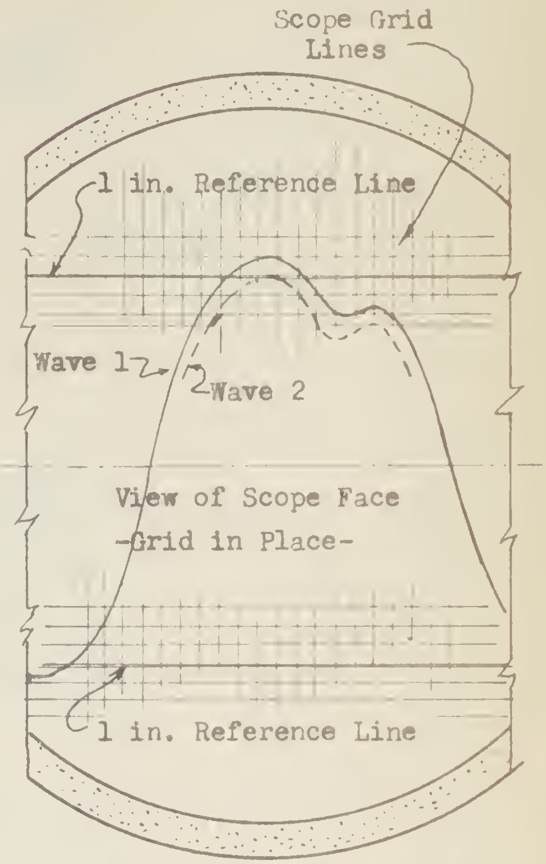


Sample 2-2



Sample 2-3

Vertical Scale Wave Amplitude Full Scale

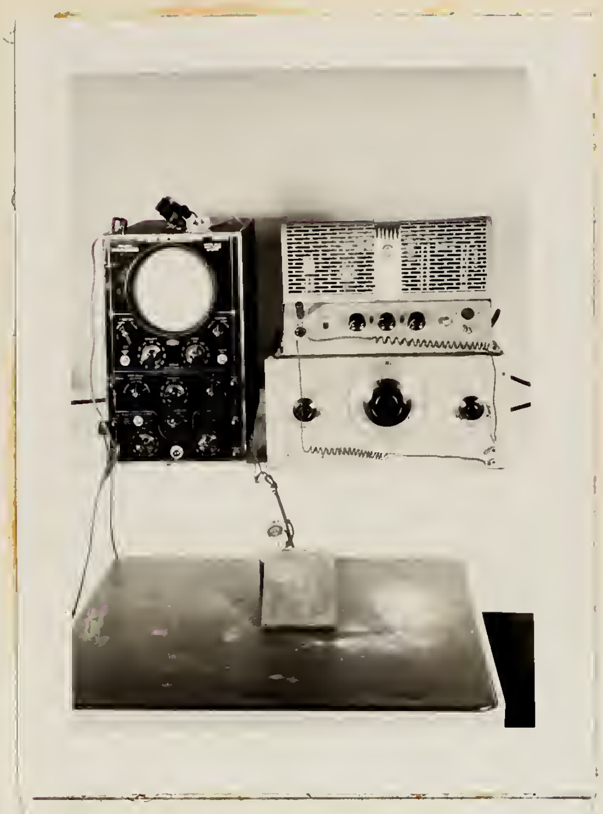


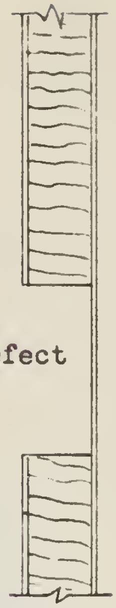
Section of Scope Showing Wave Form Appearing

1 Full Wave as it appeared - Sta. 1

2 Section of Wave Sta. 2

Fig 12a





Section
Through
Defective Area

Metal Filings Over Defective Area Sample 1-1

Fig. 13

Section
Through
Defective Area

Silicon Powder Indications Sample 2-1
See Pattern Diagram Next Page

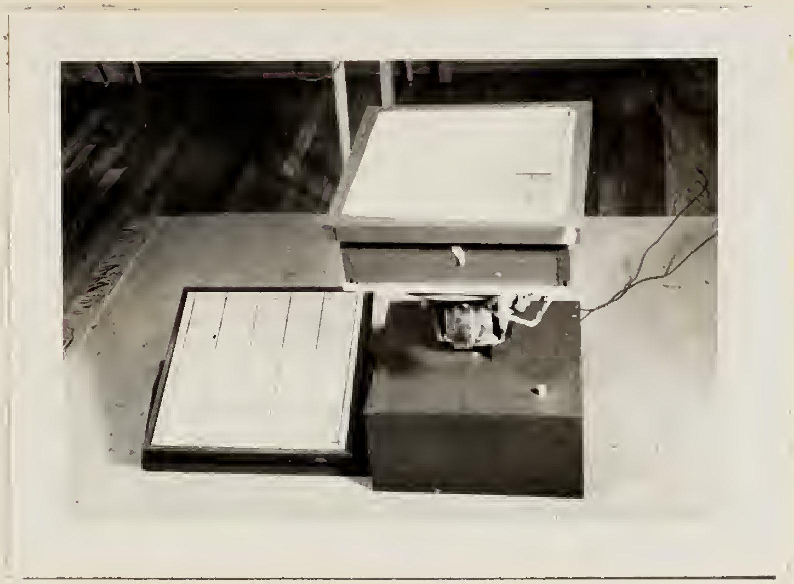
Fig. 14

2-1 2-2 2-3 5

Silicon Powder Patterns

Series 2 & 5 Samples

Fig. 14



Sample 2-1 in Smoke Chamber

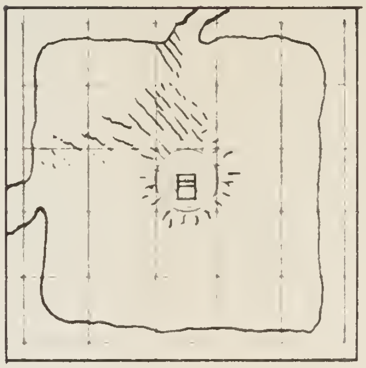
2-1 2-2 2-3

Smoke Patterns for Series 2 Samples

Fig. 15

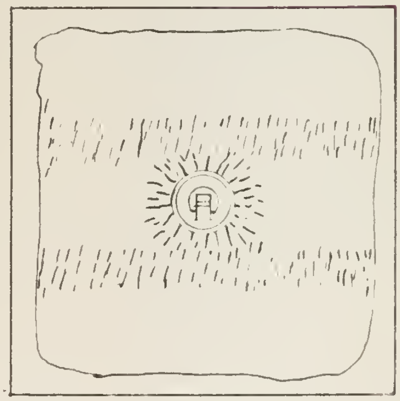
Series 2 Sample With Transducer
For Oil Pool Test

Sample 4-1 Also Used in Oil Film
Test Shown in Background



Sample 2-1

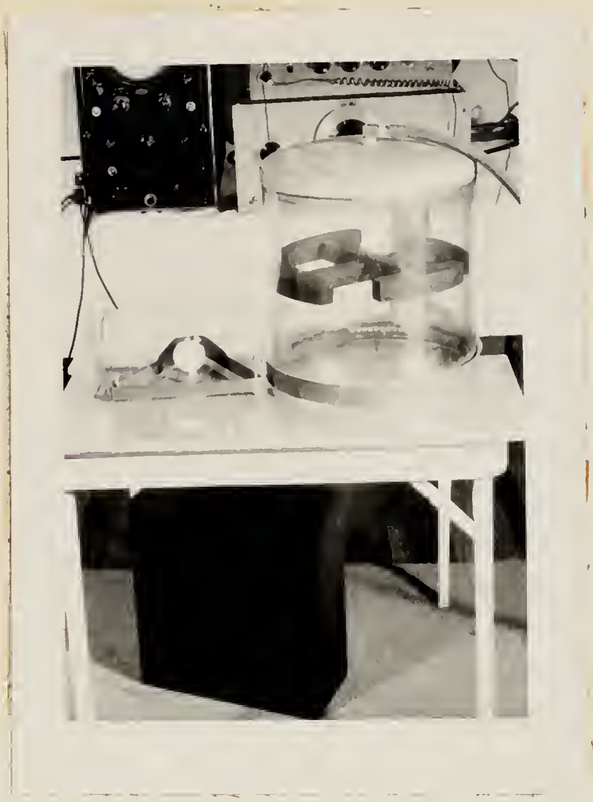
Approximate Oil Pool Coverage
Showing Points of Pool Rupture



Sample 5

Oil Pool Coverage and Approximate
Location of Ripple Bands Observed

Fig. 16



Vacuum Chamber, Ames Dial and Support Tripod

Used in Surface Deflection Method

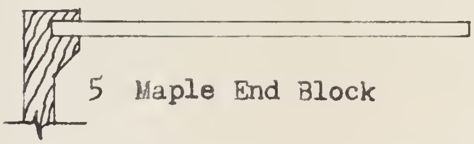
Fig. 16a

1 Wood and Glass

2 Metal Points

3 Flat Wooden Surface

4 Sponge Rubber Pads



5 Maple End Block

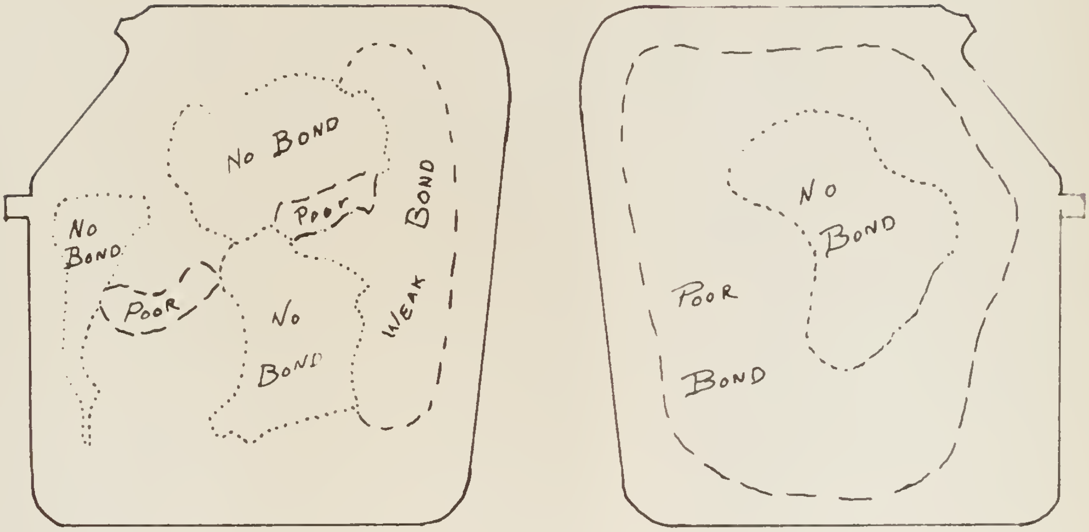
6 Steel Balls

Six Typical Supports Used in Tapping Method Tests

Fig. 17

Sample 4-3

Metalite Aircraft Door

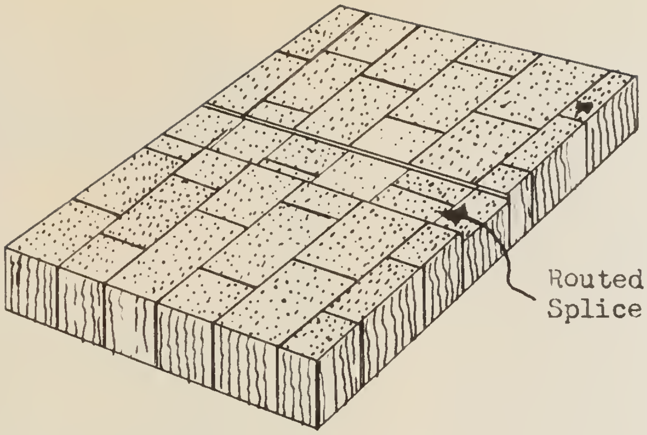


Convex Side

Concave Side

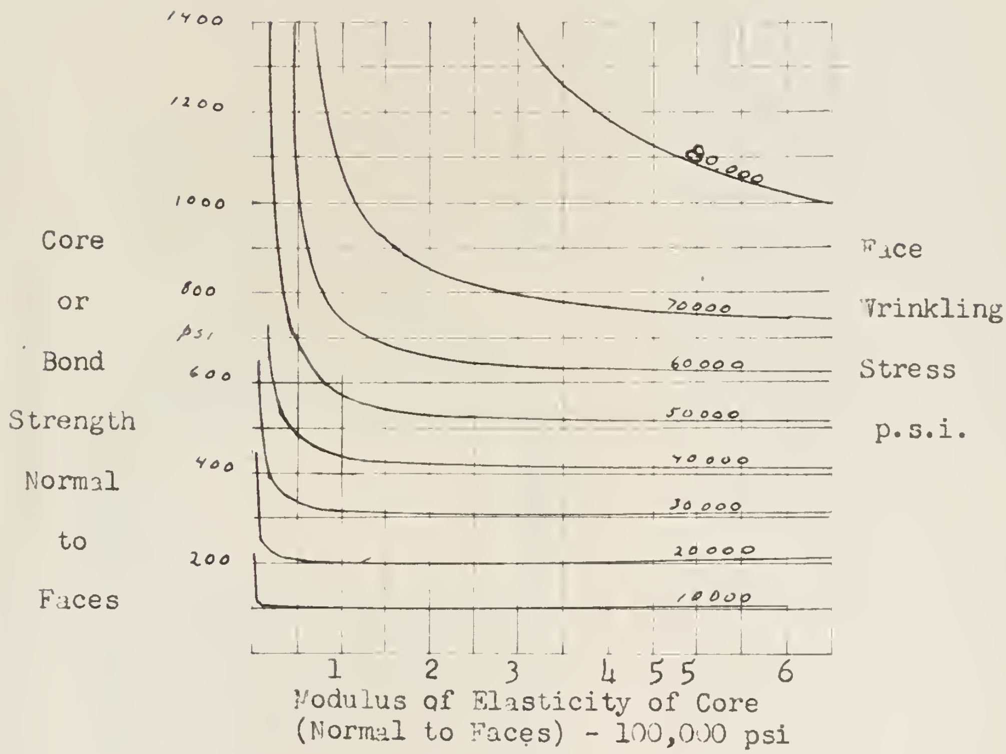
Diagram of Bond Conditions Determined by Trained Inspector Chance Vought Aircraft Corp. Dallas, Texas

Fig. 18



TYPICAL CORE SECTION

BALSA END-GRAIN Fig. 19



EFFECTS OF STRENGTH OF BALSA CORE AND BOND

ON WRINKLING STRESS OF 75S-T FACES

Fig. 20

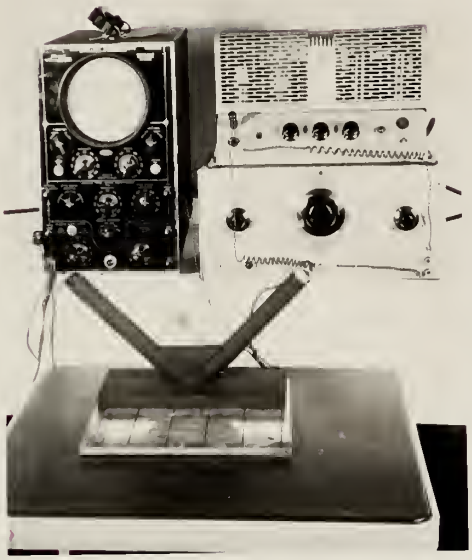
Electric Oven with Heating Cover and Sample 2-1 in Place as Used in Thermal Conductivity Tests

Upper Chamber in Place Over Heating Cover and Sample as Used for Total Panel Test.

* For Smoke Convection Method the Upper Chamber was Replaced by Glass Covered Smoke Box Shown in Fig. 15.

EQUIPMENT USED IN THERMAL CONDUCTIVITY TESTS

Fig. 21



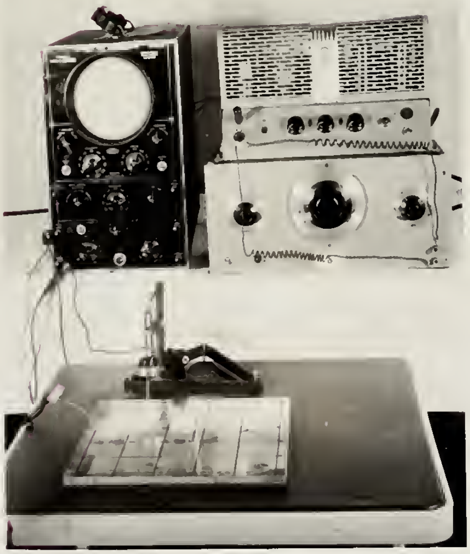
Sound Wave Reflection Test Equipment. Microphone pick-up in Left Tube and Small Speaker Unit in Right Tube.

Tubes Fixed at 45° Angle but Adjustable in Length.

Base used on various mountings for mobility.

ADDITIONAL TEST EQUIPMENT

Fig. 23

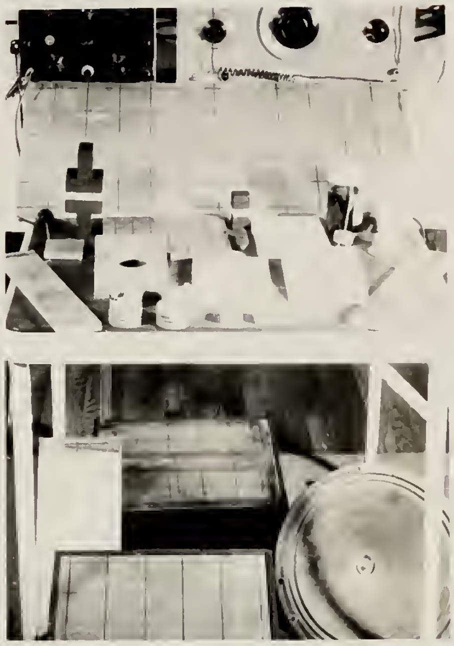


Pick-up Holder Used in Tests. Designed to vary Probe-to-Surface pressures. Mobile to explore entire surface using constant pressure.

Sample 2-1 and small transducer also shown. Note defective area outlined on sample.

ADDITIONAL TEST EQUIPMENT

Fig. 24



DISPLAY OF SAMPLES AND EQUIPMENT

Fig. 25

The Above Fig. 25 is a display of typical items used during the experiment. They Are:

Rear Above The Table

Test Sample 4-1 and the base of the Oscillograph equipment

Rear Row on the Table from Left to Right

The modified aviation microphone pick-up

A 2 in by 2 in test biscuit and another biscuit mounted in a frame for tension testing

A scrap-material sample used in the heating tests

A 1 in. by 1 in. test biscuit in testing frame

A C O_2 container used to frost surfaces

One 4 in by 6 in balsa core ready for assembly

A bottle of Redux liquid and a bottle of Redux powder

The magnetic and dynamic transducers

Center Row

A sample of Metalite with a circular biscuit removed.
(this is the type sample Chance Vought uses)

A second Balsa Core with a circular test biscuit on it

A surface sheet of Aluminum coated with Redux liquid and powder - dried ready for assembly.

Front Row

A test sample 3-1

Two broken circular test biscuits

Two 1 in. by 1 in. test biscuits taken from test samples

The control strip of series 3 samples

Under the Table

Rear is the Blast box with sample 2-1 in place on it

In front left is the control panel of series 2 in place on the adjustable mounting rack

Right is the 10 in. dynamic speaker used to obtain the sound wave fields used in the tests